Littlerock Dam
Little Rock Vicinity
Los Angeles County
California

HAER No. CA-8

PHOTOGRAPHS

HISTORICAL AND DESCRIPTIVE DATA

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HISTORIC AMERICAN ENGINEERING RECORD

Littlerock Dam

Location: Foothills of San Gabriel Mts. on Little Rock Creek near the town of Littlerock, Los Angeles County, California

Date of Construction: 1922-1924

Present Owners: Littlerock Irrigation District and Palmdale Water District

Present Use: The dam impounds the runoff of Little Rock Creek for use in irrigating the orchards of Littlerock. It is also used as a source of water supply for filling Palmdale Lake near Palmdale.

Significance: When built the Littlerock Dam was the tallest reinforced concrete multiple arch dam in the world. For over fifty years it has provided water for the South Antelope Valley and contributed to the valley's economic development.

Historian: Donald C. Jackson, February 1981

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ACKNOWLEDGEMENTS

Preparation of this report has been undertaken by the Historic American Engineering Record (HAER) as part of its program to document America's engineering and industrial heritage. HAER's collection is maintained by the Prints and Photographs Division of the Library of Congress in Washington D.C. and it is available for use by the general public. Documentation of the history of America's water resources development comprises an important part of HAER's mission and this report represents, in part, our interest in late 19th and early 20th century irrigation history in the West. It focuses on a specific example of irrigation development in California but many of the issues it raises are relevant to water resources development on a broad scale.

This report is not the "last word" on the history of the Littlerock Dam. Instead, it is intended to serve as a stepping stone for future researchers interested in learning more about the history of the South Antelope Valley, irrigation districts in southern California and early 20th century dam design in California. This report provides: a brief description of the Littlerock Dam; background on the history of the Littlerock and Palmdale Irrigation Districts; a synopsis of the engineering career of John S. Eastwood; and an outline of the events involved in the design, approval, and construction of the Littlerock Dam between 1918 and 1924. In order to limit the length of the text it has not been possible to discuss all aspects of the dam's history in equal detail, but the author believes the general nature of the dam's history has been well covered.

The assistance of Mrs. Hobart Bosworth, a long time resident of Littlerock who possesses great knowledge concerning the history of Southern California, was very valuable in the preparation of this report. Mrs. Bosworth's insight into the workings of California's economic and political life provided the author with a useful context in which to assimilate and comprehend the extensive records that this report is based on. The staffs of the Littlerock Irrigation District, the Palmdale Water District, the Water Resources Center Archives of the University of California, and the Lancaster Public Library also assisted the author in preparing this report. Finally, the efforts of the Citizen's Committee to Save the Littlerock Dam Inc. to bring public attention to the value and historical significance of the dam are gratefully acknowledged. The Citizen's Committee provided funding to the Historic American Engineering Record to support completion of this report. Without their cosponsorship this project would not have been possible.

Description and Introduction

Over 690 feet long and extending at least 170 feet from top to deepest foundations, the Littlerock Dam is among the largest and best preserved reinforced concrete multiple arch dams in the United States. Designed by John S. Eastwood, the Littlerock Dam was built for the Littlerock and Palmdale Irrigation Districts between late 1922 and early 1924. Since that time it has impounded the run-off of Little Rock Creek,* a stream flowing out of the Northern slope of the San Gabriel Mountains, for use in irrigating the orchards in the Littlerock Creek Irrigation District as well as for supplementing the water needs of the Palmdale Water District. Beyond being of great historical significance in the development of the South Antelope Valley, the dam is also significant in the history of structural engineering. At the time of its construction it was the tallest reinforced concrete multiple arch dam in tne world.

To many people, one dam is the same as another, and they give little thought to differences in design among the thousands of water storage structures tnrough- out America. However, the Littlerock Dam has a distinctive appearance that would probably strike even the most casual observer as something different from their idea of a "typical" dam. It is not just a huge mass of concrete, rock or earth that, by virtue of its great mass, is able to hold oack and store the flow of Little Rock Creek. It is a structure designed and proportioned in a manner that allows a relatively small amount of reinforced concrete to impound a great height of water.

* Readers should be aware that the stream is referred to historically as Little Rock Creek while the irrigation district and community have almost always been referred to as Littlerock. The dam is usually referred to as the Littlerock Dam, though it has also been referred to as the Little Rock Creek Dam and the Palmdale Dam.

The Littlerock Dam is known as a multiple arch dam because it uses a series of arches to form its upstream face.[1] These reinforced concrete arches, or cylindrical arch rings, extend from the too of the dam down to the bedrock foundations. They are sloped at an angle of 45^{o}, except for the top 10 feet which are vertical, and comprise the barrier that holds back the run-off of Little Rock Creek. The 28 arches emcompass an arc of 100^{o}, have a span of 24 feet, and vary in thickness according to their position in the dam. At tne top of the dam, where the pressure of the stored water will always be at a minimum the arches are 15 inches thick. As the arches extend downward the maximum possible water pressure on them increases and they gradually increase in thickness until, at the deepest portion of the dam, they are 4 feet 7 inches thick.

The arches are supported by 29 buttresses spaced 24 feet apart. These buttresses are founded firmly on bedrock. These buttresses are only visible when looking at the downstream side of the dam. Like the arches they also vary in thickness according to their elevation. At the top, the buttresses are 15 inches thick while at the deepest portion of the dam they increase to a thickness of 4 feet 9 inches. When the dam is filled with water, the hydrostatic pressure exerted by the reservoir is borne by the arches and concentrated on the buttresses. It is through the buttresses that tne water pressure is then distributed to the dam's foundations.

The downstream edge of the buttresses is formed into a "T-section" that provides the buttresses with additional lateral stability. Perpendicular to the buttresses are a series of strut-tie beams (horizontal reinforced concrete members) that run continuously through the dam and provide the structure with additional lateral stability. In spite of the strut-tie beams visual prominence, they are of relatively minor significance in the operation of the design as they do not contribute to the dam's strength in resisting normal hydrostatic pressures.

Water from the reservoir is released into the irrigation flume via an outlet valve located in the arch between two of the tallest buttresses. During years of heavy run-off, the reservoir can become full and water will pour over the spillway at west end of the dam. The present overflow spillway is not part of the original design and represents the only substantial alteration to the dam in the last 56 years. The dam originally had a siphon spillway but this was damaged during the heavy storms of March 1938 and was subsequently replaced by the present arrangement. Aside from this, the Littlerock Dam stands essentially as it did in 1924. Within the dam there is a large quantity of reinforcing steel. In August 1924, the Southwest Builder and Contractor reported that 526 tons of reinforcing steel were placed in the dam, along with 25,000 cubic yards of concrete.[2] This steel was placed in the arches, the buttresses, the strut-tie beams, and the siphon spillway.

Conceptually, the most important thing to realize about the design of the Littlerock Dam is that the up-stream sloping of the arches and buttresees plays a significant role in the stability of the structure. Because the upstream face is sloped. the water stored by the dam exerts a vertical force on the dam that contributes greatly to its safety. It is also important to note that the arches, as well as the buttresses, are designed so that the water pressure can only exert compressive forces on the dam.

Finally, the design of the Littlerock Dam is distinguished by the presence of an angle in the dam of aoout 165^{o}. This angle does not affect the staoility of the structure, but it did allow a considerable amount of concrete (and consequently money) to be saved as a result of the topographic layout of the dam site. The Southwest Builder and Contractor reported that the angle was designed into the dam "to avoid carrying the foundations of the structure down into a deep chasm on the upstream side which would have been intersected by the dam if built on a straight line."[2] The Littlerock Dam was the first multiple arch dam in the world built with such an angle in it, but other multiple arch dams have been built that employ similar angles, and the best known is perhaps the Florence Lake Dam that is part of Southern California Edison's Big Creek Hydroelectric complex east of Fresno.

Construction of the Littlerock Dam came about as the result of two things: 1) A desire on the part of farmers in the South Antelope Valley to increase their ability to beneficially use the run off of Little Rock Creek and 2) The fulfillment of this desire by the use of a dam technology developed by John S. Eastwood. During the late 19th and early 20th centuries the value of dams in storing water for use in times of dry weather was well appreciated by Western farmers, including those farmers in the South Antelope Valley. This report focuses on the design, approval and construction of the Littlerock Dam but it also provides background of the history of the Littlerock and Palmdale Irrigation Districts and on the history of the engineer who designed the dam. Without such background it is difficult to understand the complete significance of the structure.

[1] For general references on the design of the Littlerock Dam, see "Highest Multiple Arch Dam in the World Is Constructed Under Great Difficulties," Southwest Builder and Contractor, August 22, 1924, pages 44-46; and Edward Wegmann, The Design and Construction of Dams (New York, John Wiley and Sons, 1927), pages 486-490.

[2] Southwest Builder and Contractor, August 22, 1924, page 46.

Early History of the
Littlerock and Palmdale Irrigation Districts

On March 7, 1887, the California State Legislation passed the Wright Act in order to promote irrigation in the State. As described in a California Department of Engineering bulletin, this law:

> "...sought to confer on farming communities powers of municipalities in the purchase or construction and the operation of irrigation works. Those powers included the right of eminent domain, the right to issue bonds against all of the real property within any area organized into an irrigation district, and the right to tax that property for the payment of the cost of any irrigation works acquired or built and of their operation"[1]

Championed by C.C. Wright, a lawyer from Modesto, this law was seen as a victory for small-scale farmers over large land owners. The Wright Act provided "for community ownership and operation of irrigation works," and during the next ten years forty-nine irrigation districts were established throughout the State.[2] Among these was the Littlerock Creek Irrigation District in the Antelope Valley, a district formally established on March 28, 1892.[3]

Following the arrival of the Southern Pacific Railroad in 1876, the Antelope Valley became fairly accessible to markets in Los Angeles and the San Francisco Bay area, and a few farmers began agricultural cultivation dependent upon natural precipitation.[4] Not surprisingly, the importance of developing irrigation facilities became quickly apparent as rain fall proved to be inadequate. Under the authority of the Wright Act, six irrigation districts were formed in the Antelope Valley, even though the great drought of the 1890's led to the economic demise of most of them. In the Antelope Valley only the Littlerock Creek and the Big Rock Creek Irrigation Districts survived past 1915.[5] As with many of the other districts in California, the Littlerock Creek Irrigation District was considered to be speculative in the sense that it was formed in order to entice settlers to invest in land served by the district.

The first group of farmers to use Little Rock Creek took advantage of an interesting geological phenomena that provided them with a fairly constant, if not infallible, source of water. As described in a 1911 publication by the United States Geological Survey, the San Andreas Fault crossed Little Rock Creek in close proximity to the Littlerock Creek Irrigation District, and

> "for nearly five miles above this point the stream bed is dry during a large portion of the year...[However] the north side of the fault seems to act as a submerged dam and the underflow of the creek has been forced to the surface. A flume was submerged into the gravels of the creekbed at this point, through which much of the underflow was led to a canal on the east side of the creek."[6]

It was via this canal that the orchards of the irrigation district received their water.

Although development of the Littlerock Creek Irrigation District suffered because of the great drought of the 1890's, the district never ceased to function in some capacity and today is one of the oldest irrigation districts in the entire State. In 1908 it was described as "...in a more prosperous condition than any of those depending upon surface waters for irrigating in the Antelope Valley. About 250 acres of pears, 200 acres of apples and 50 acres of almonds are under cultivation..."[7] By 1910 it had become clear that the district had survived the great drought and that it comprised a financially viable agricultural enterprise.

The official establishment of the Palmdale Irrigation District did not occur until 1918, but even at that time, there existed a precedent for the diversion of water from Little Rock Creek to the Palmdale area.[8] In the 1890's the South Antelope Valley Irrigation Company was formed in order to divert water from Little Rock Creek to the site of the present Harold Reservoir (or Lake Palmdale) via a 7 mile long open ditch.[9] The geography of the site formed a "depression" that was readily adopted into a natural reservoir with a capacity of over 5,000 acre feet. Quite naturally, the farmers of the Littlerock Creek Irrigation District considered this an intrusion upon their water rights and resisted the development. However, an agreement was reached whereby the Littlerock Creek Irrigation District retained rights to the first 650 miners' inches of water in the creek and allowed the South Antelope Valley Irrigation Company to use any in excess of this.[10] /Note: A miners' inch was measurement of water flow that originated in the era of gold mining. In California 650 miners' inches equals a flow of 13 cubic feet per second. (See: David S. Gray, How to Measure Running Water, Grand Junction, Colorado: published by author, 1904), pages 10-11/

Apparently the company prospered for a short time, but because of the seepage loss caused by its 7 mile long, unlined canal and the "dry winters" of the late 1890's and early 1900's, the company and its scheme folded. However, inspite of its ultimate failure, this project established an important precedent for landowners in the Palmdale area to become involved in using water from Little Rock Creek and almost certainly contributed to the establishment of the Palmdale Irrigation District in 1918.

It is not exactly clear when the construction of a storage dam on Little Rock Creek was first proposed, but almost certainly the advantanges of such a facility were evident from the inception of farming in the Littlerock area.[11] A storage dam would allow the spring runoff from over 60 square miles of the San Gabriel Mountains to be "captured" before spilling out on the desert floor of the Antelope Valley. It could then be distributed to the orchards throughout the late spring and summer months. No longer would the farmers of Littlerock be dependent upon the underground flow of precipitation in Little Rock Creek Basin. However, dams are expensive to build and it wasn't until John S. Eastwood began acquiring a reputation as a designer of inexpensive reinforced concrete dams that farmers in the South Antelope Valley began to think that construction of a dam on Little Rock Creek was perhaps more than a dream.

FOOTNOTES

1) Frank Adams, Irrigation Districts in California 1887-1915, State of California Department of Engineering Bulletin No. 2., (California State Printing Office, 1916) page 8.

2) Ibid, page 5 and page 9.

3) Antelope Valley Times, April 28, 1892 page 1, (on microfilm at Lancaster Public Library). An article in this issue of the Times indicates that the Littlerock Irrigation District board of directors voted an April 6, 1892 to hold a special bond election for irrigation improvements. The district's seal indicates that the formal organization had occurred a little more than a week before on March 28.

4) Alan Gale Stones, Antelope Valley, Mojave Desert, California: a Geographical Analysis, (Unpublished Master's Thesis, University of California, Los Angeles, 1964) page 197.

5) Adams, Irrigation Districts in California, page 60.

6) Harry R. Johnson, Water Resources of Antelope Valley, California, United States Geological Survey Water Supply Paper No. 278, (Government Printing Office, 1911) page 34.

7) Ibid, page 35.

8) Antelope Valley Ledger Gazette, July 12, 1918 (on microfilm at Lancaster Public Library).

9) Johnson, Water Resources of Antelope Valley, California, page 33.

10) Ibid, page 34.

11) Antelope Valley Ledger Gazette, November 30, 1917, page 1 An article entitled "Big Water Project Plan for Palmdale" appeared in this issue and noted plans for a dam on Little Rock Creek that would provide water for both the Littlerock Irrigation District and the Palmdale Land and Water Company, a predecessor of the Palmdale Irrigation District.

John S. Eastwood

Although his name appears rarely in books on California history, John S. Eastwood played an important role in the development of the State from the 1890's until his death in August 1924. Engineers rarely share the "historical spotlight" with politicians, financiers, or other public figures, but without them the physical growth and development of our nation would have been impossible. For more than 50 years the social and economic life of the South Antelope Valley has blossomed, in large part, because of the benefits afforded by the Littlerock Dam. Yet, practically no one in the valley knows much aoout the man who designed the dam or the experiences in his engineering career that fostered his interest in designing multiple arch dams.

Born in Minnesota in 1857, Eastwood grew up there and matriculated from the University of Minnesota. Upon graduation as a civil engineer in 1880 he went west to work on railroad construction in the Pacific Northwest. Three years later he moved south to the Central Valley of California. Arriving in Fresno at he age of 26, Eastwood set up shop as a civil engineer and surveyor. The majority of his work involved surveying and his experience in laying out streets and property lines led to his becoming Fresno's first city engineer in 1885. However, his interest in being a municipal engineer waned and he gave up the position after a relatively brief tenure. Eastwood believed the great natural resources of the Sierra Nevada Mountains east of the city provided an opportunity for him to implement engineering projects far greater in scope than anything Fresno proper could offer. It was while on the construction of a large lumber flume in the Sierras that he became cognizant of the great hydro power potential inherent in the region's mountain streams.

Eastwood's first major project was the design and construction of the San Joaquin Electric Company (SJEC) hydroelectric plant on the North Fork of the San Joaquin River northeast of Fresno in 1895-96.[2] This was the world's pioneer high-head hydroelectric plant and brought Eastwood considerable recognition as an innovative and resourceful engineer. The SJEC's installation included a seven mile long canal/flume; a steel penstock over 4,000 feet long that dropped over 1,400 feet from the canal at the top to the power station at the bottom and delivered water to high speed Pelton Turbines at a pressure of over 600 pounds per square inch; a three phase alternating current power station that was among the most advanced in the world when first put on-line in the spring of 1896; and a 34 mile long, 11,000 volt transmission line to carry the power generated by the plant to the sub-station in Fresno where it was distributed to the city and its environs.

Technologically, the SJEC facility was a great success, but financially it did not fare as well. The company did not have sufficient capital to construct both the power plant and a dam on the North Fork of the San Joaquin River to store water for use at a time when the river might temporarily dry-up. The great California drought of the late 1890's could not have occurred a a worse time for the SJEC and, though the company tried to keep enough water in the penstock to power the turbines, the flow of the San Joaquin River's North Fork proved insufficient for this purpose. Consequently, the SJEC went bankrupt in 1899 and its facilities were bought by other financial interests. The new

owners realized that Eastwood's system comprised a financially viable enterprise if it could be provided with a reliable sorce of water. This water source was provided for by constructing the Crane Valley Dam that now forms Bass Lake. Although Eastwood's 1896 power house is presently only used as office space next to Pacific Gas and Electric's (P.G. & E.'s) more modern Wishon power station on Lake Kerchoff, the system Eastwood envisaged in the 1890's is still part of P.G. and E's hydroelectric power network.

Following the financial collapse of the SJEC, Eastwood plunged ahead with plans for developing hydroelectric plants on the rest of the San Joaquin River. In the early 1900s he was able to convince Henry Huntington's Pacific Light and Power Company (P.L.&P.C.) that a huge hydroelectric system could oe built in the Sierra Nevada Mountains east of Fresno. His scheme included a series of power plants constructed in a number of locations that would allow the water to be used successively for a total drop of more than 5,000 feet. This system is today known as Big Creek and is owned by the Southern California Edison Company. The project began in 1902 and Eastwood, as chief engineer, was responsible for its complete design.[3]

Eastwood did not want another of his projects brought to financial ruin because of an unforeseen drought, and he devoted considerable energy to developing a type of dam that could be built relatively inexpensively in the remote reaches of the mountains. During the planning stages of this project Eastwood developed ideas for the reinforced concrete multiple arch dam. Between 1902 and 1907 Eastwood completed the mammoth task of working out the numerous design

problems associated with Big Creek, but, as a result of Huntington's business circumstances, actual construction of the project was delayed until the financial magnate deemed it appropriate. In 1908, while waiting for the "go-ahead" on Big Creek, Eastwood contracted with the Hume-Bennett Lumber Company to build a 64 foot high multiple arch dam on a tributary of the Kings River to facilitate operation of a saw mill.[4]

The Hume Lake Dam was the first reinforced concrete multiple arch dam in the world built on bedrock foundations and is still operated today by the U.S. Forest Service for recreational purposes. Economically, the multiple arch design was a great success and shortly after completion of the Hume Lake Dam, Eastwood received the design contract for the 92 foot high New Big Bear Valley Dam in San Bernardino County. This dam is also still in operation.[5]

In late 1910, during construction of the New Big Bear Valley Dam, Huntington chose to proceed with construction of Big Creek and, for reasons that remain unclear, Eastwood was notified by the P.L. & P.C. that he had been relieved of his position as chief engineer for the project. Although this eliminated his direct involvement in the construction work, Eastwood still retained a financial interest in the project because he held 10% of P.L. & P.C. stock. However, in order to finance construction of Big Creek, Huntington, who controlled a majority of P.L. & P.C. stock, decided that all P.L. & P.C. stockholders were to be assessed to pay for the project's construction costs.

Aside from his stock Eastwood had no substantial assets and, consequently, he was placed in a position where the only way he could pay the assessment was to sell his stock. As Redinger wrote in the The Story of Big Creek, "at last he lost everything."

In 1913 Eastwood was 56 years old, and in spite of the prodigous contributions he had made to California's development of hydroelectric power, he had no financial cushion to fall back on. Having no other real professional options open to him he moved to San Francisco to establish himself as a consulting engineer specializing in the design of multiple arch dams. He worked hard to prove the economic advantages of his multiple arch designs and began building a reputation as a dam engineer. Following his successes at Hume Lake and Big Bear Valley, Eastwood designed two mining debris dams built in northern California as well as the Los Verjeles Dam near Jackson, California. He made an effort to publicize his accomplishments in the journal Western Engineering, and, in 1915, the Salt Lake City Engineers Office selected one of his designs for their 150 foot high Mountain Dell Dam.

The utility of Eastwood's dam designs was rapidly becoming apparent and by 1916 his consulting business was beginning to expand significantly. At this time he began working with a consortium of financial interests in San Diego County organized by Colonal Ed Fletcher, and during the next two years four of his dams were built in the County. These were Lake Hodges Dam (originally called Carroll Dam), Lake Murray Dam, San Dieguito Dam, and Eagles Nest Dam (a small structure on the Fletcher Estate near Warners Springs).

The economic success of these dams brought Eastwood even more attention.[6] At this time farmers in the Littlerock area became interested in having him design a dam to impound the waters of Little Rock Creek.

As discussed in the next chapter, Eastwood designed three different dams at two different locations on Little Rock Creek between 1918 and 1922. During this time he expended considerable energy in attempting to convince the California State Engineer to approve his Littlerock Dam designs, but it was by no means the only project he was involved in. He received commissions for dams in Idaho and Arizona, but the Littlerock Dam was of special interest to him because it was to be the tallest in the world at the time.

When the Littlerock Dam was finally approved for construction in late 1922, Eastwood was already deeply involved in numerous other dam projects in California, Canada and Mexico. He did not supervise the construction of the Littlerock Dam (this was left completely in the hands of the contractors, Bent Brothers), but he did keep abreast of its progress and made trips to inspect it. Sadly, completion of the dam in the late spring of 1924 preceded Eastwood's death in August of the same year by only a few months. However, Eastwood did receive the satisfaction of knowing that, after becoming involved in the dam's design six years earlier, his plans had finally become a reality.

FOOTNOTES

1) For biographical information on John S. Eastwood readers are referred to: Charles Allen Whitney, "John S. Eastwood, Unsung Genius of the Drawing Board," Montana, the Magazine of Western History 19 (Summer of 1969) and Donald C. Jackson, "John S. Eastwood and the Mountain Dell Dam," Journal of the Society for Industrial Archeology, 5 (Summer 1979). In the early 1970's Mr. Charles Allen Whitney also prepared an unpublished manuscript entitled "The Life and Times of John S. Eastwood," a copy of which may be found at the Fresno City and County Historical Office in Fresno, California.

2) For more information on the San Joaquin Electric Company see, George P. Low, "The Fresno Transmission Plant" Journal of Electricity (April 1896).

3) David H. Redinger, The Story of Big Creek, (Los Angeles, CA., 1949) pages 4-9.

4) See "The Hume Lake Dam," Journal of Electricity, Power and Gas, 23 (October 30, 1909).

5) See John S. Eastwood "The New Big Bear Valley Dam," Western Engineering 3 (December 1913).

6) The best general reference on early multiple arch dams is, Edward Wegmann, The Design and Construction of Dams, (New York 1927). The eighth edition of this famous book includes a special section devoted solely to multiple arch dams.

APPROVAL OF THE DESIGN

This chapter summarizes the protracted negotiations that preceded the California State Engineer's approval of a dam designed by John S. Eastwood to impound the waters of Little Rock Creek. Though extensive documentation related to the dam's construction survives it is evident that considerable amounts of relevant correspondence have been either misplaced or destroyed. However, in spite of gaps and lacunas it is possible in large part to reconstruct the major events that occurred relative to the State's approval of a multiple arch dam on Little Rock Creek. Although the history is complicated by the fact that three different Eastwood dam designs were proposed for two different sites in the Little Rock Creek Canyon, the chronology of events is usually clear and demonstrates the persistant efforts of the Littlerock and Palmdale Irrigation Districts to more fully develop the water resources of Little Rock Creek.

In late 1917 plans for a large storage dam on the Little Rock Creek were first announced in the Antelope Valley Ledger Gazette.[1] However, it wasn't until April 5, 1918 that John S. Eastwood signed an agreement with the Littlerock Creek Irrigation District and the Palmdale Water Company to provide "...full and complete plans, detailed drawings and specifications for such dam to be of the multiple arch type of a height of approximately 182 feet..."[2] Soon afterwards plans for this structure were forwarded to Wilbur F. McClure, California State Engineer, and on May 23 the State Department of Engineering wrote Eastwood acknowledging receipt "...of a set of blue-prints of the plans for (the) proposed Little Rock Creek Dam."[3] Though the letter indicated that "the matter will receive prompt attention" it was not until over 4 years later, in November 1922, that McClure finally gave complete approval for an Eastwood designed dam in the Little Rock Creek Canyon.

In 1917 the California State Legislature enacted a dam safety law that stated:

> "All dams in the state of California, other than those for impounding mining debris constructed under the authority of the California debris commission, or dams constructed by a municipal corporation maintaining a department of engineering, shall be under the authority of the state department of engineering, and the department shall exercise supervision over any dam, the failure of which would endanger life or property, and shall have power to prescribe and enforce compliance with measures for making such dams safe against failure; provided, that this section shall not apply to any dam which is part of a water system as defined in section two of the public utilities act of this state, and nothing in this act shall be construed to limit the jurisdiction of the railroad commission over such dams. [and that] It shall be unlawful for any person, firm, corporation or district to construct, maintain or operate any dam known to be unsafe or which if the destruction or failure thereof would endanger life or property; or to construct, reconstruct, repair or improve, maintain or operate any dam which is or would be ten feet or more in height or which will impound water or other fluid to the amount of three million gallons unless the plans specifications and construction thereof shall have been approved in writing by the state department of engineering."[4]

In essence this act required any group or person who wanted to build a dam of any substantial size in California to receive the approval of the State Engineer unless they were a public utility or municipal government with an engineering department. There could be no exception to this rule. It was for this reason that McClure's approval was being sought for the Littlerock Dam.

During the Summer of 1918 little was done concerning the proposed Littlerock Dam but by the end of September McClure notified Burt Cole, Engineer for the Palmdale Irrigation District, that he would "...be pleased to approve plans for your proposed multiple arch type dam in Little Rock Canyon with minimum thickness of 15 inches for the top members."[5] Unfortunately for persons interested in the agricultural development of the Antelope Valley, McClure completely changed his mind within less than 2 months and on November 26 wrote Cole that, on the basis of a "short statement" from an employee in his department and a report by an unidentified engineer, he was "...fully persuaded that no dam of this type [i.e. multiple arch] should be built to a greater height than from 140 to 150 feet."[6] Beyond this McClure gave no reasons for changing his mind. Not unexpectedly, Eastwood was upset by the turn of events and on November 27 wrote Cole expressing his disappointment over McClure's recent decision. In this letter Eastwood commented that the rejection of his design was:

> "...apparently all a trumped and inspired thing to knock out your districts for there is no truth in any of the statements in either of the reports. If you do not build a multiple arched dam, you cannot build any kind of dam, for no type can be built within the economic limits of your bonding limit, and no type of dam of any kind can be built for the cost of the multiple arched dam. So then your fields can lie dry and there will be no life or property which might be in the path of the torrent which would be released upon the failure of such a dam,' an undisturbed home for the horned toad and jackrabbit'."[7]

Eastwood provided Cole and McClure with a detailed response to the criticism of his design but this had no discernable effect on the State's position.

Following the State Engineer's unexpected rejection of the first Eastwood designed dam for Little Rock Creek, a new tact was taken by the Districts that would not require the State Engineer to approve the dam's design. Under the 1917 legislation the State Engineer was given the authority and responsibility of approving all dams over 10 feet high (or able to impound more than 10 acre feet of water) unless they were built by a municipality with a department of engineering or unless they were to be built by a public utility under the regulation of the State Railroad Commission. As outlined in a letter by William Petchner, attorney for the Palmdale Irrigation District, plans were devised whereby the Palmdale Water Company (a public utility regulated by the State Railroad Commission) would build the dam and then transfer it to the Palmdale and Littlerock Irrigation Districts.[8] The State Railroad Commission still had to approve the design, but both the Districts and Eastwood believed they would be inclined to do so. State Engineer McClure agreed that this was an acceptaole course for the Districts to follow.[9]

Throughout the first half of 1919 the District pursued this plan. Eastwood developed his second design for Little Rock Creek, a new type of design he called a radial cone multiple arch dam. In this the arches of the dam were not cylinders but instead, were tapered in towards the bottom of the dam in the shape of a cone. This reduced the stresses in the lower part of the dam and enaoled the amount of concrete required to be reduced, thus lowering the cost. Neither Eastwood nor anyone else had ever built any radial cone multiple arch dams prior to this, so it was an exceptional design. Regardless, the State Railroad Commission moved quickly to act on its acceptaoility.

In January 1919 the Palmdale Water Company filed an application with the State Railroad Commission for permission to construct a multiple arch dam in Little Rock Creek Canyon. On March 3 the Commission held a public hearing on the application and on March 28 they specifically requested the State Engineer to provide them with comments on the new dam design.[10] During the next several weeks McClure's office conferred with Eastwood, undertook an internal review of the plans and asked for the opinion of two engineers outside the State government on the suitability of Eastwood's design. Though the State Railroad Commission was empowered to act on their own it is clear that the opinion of the State Engineer's office was important to them.

The internal review of Eastwood's plans by the State Engineer's office indicated their opinion that the design should not be built. A similar opinion was made by Mr. W.L. Huber, a consulting hydraulic engineer, in response to a request by McClure to review the plans. Basically both Huber and the State Engineer's staff criticized the "downstream arch" of the dam and the fact that its height of 180 feet was unprecedented for multiple arch dams.[12] These opinions were conveyed to the Railroad Commission and considered by them in making a decision on the Palmdale Water Company's application. In early June the Commission made its decision on the application and approved it, providing that the State Engineer's office also approved of the details of the dam's design. Consequently this placed the State Engineer in the position of being able to decide whether the structure should be built or not. On June 21, 1919 W.L. Huber wrote to McClure and indicated his chagrin that "...the Railroad Commission had rendered a

decision permitting Mr. Eastwood to go ahead with his Palmdale Dam." But he also indicated that he did not see how McClure could approve the details of the dam given the State Department of Engineering's opinion of the complete design and counseled that "...you should (not) be compelled to assume such responsibility..."[13]

Upon learning of the Railroad Commission's decision the Littlerock and Palmdale Irrigation districts quickly grasped its implications and began working on a new course of action. On June 14, 1919 Petchner wrote McClure and proposed that consideration be given to approving a normal multiple arch dam (i.e. not a radial cone design) for a new site on Little Rock Creek Canyon that would require a structure approximately 150 feet high.[14] This letter also noted that McClure had only rejected the first Eastwood multiple arch dam design for Little Rock Creek Canyon because it had exceeded 150 feet. The new site had been first surveyed by J.B. Lippincott in 1915 but, apparently because of distractions caused by World War I, had been forgotten. Petchner indicated that no part of the newly proposed design would extend more than 150 feet above the stream bed, although the structure would have extended another 15 feet or so down to bedrock. In essence, Petchner recognized that McClure would not approve the "details" of the radial cone design as required by the Railroad Commission. He also realized that McClure would have to be presented with an option that would allow him to approve a dam design for Littlerock Creek without requiring him to contradict his earlier statement or opinions. The discovery of new dam site that would not require an excessively tall dam provided the irrigation districts with new hope.

During the summer of 1919 Eastwood began working on a design for the new dam site although his work was some what impeded by the lack of a precise topographic map covering the new site.[15] Even at this time Eastwood was still contemplating the construction of a "radial cone" multiple arch dam but he was also working on a "straight crested" design that appeared would be more readily approved by the State Engineer. Interestingly, he was also contemplating the construction of two dams, one at the original site and one at the second site, an idea which was apparently considered for some time though no real action was ever taken to implement it.[16]

On September 17, 1919, C.I. Rhodes, Assistant Engineer for the State Railroad Commission, made an inspection of the new dam site and reported to the Commission that he could see "no reason why this site should not prove satisfactory" for a multiple arch dam. He indicated that the granite bed rock at the site appeared to be of very good quality and that the material that would have to be excavated to reach bedrock in the stream bed appeared to be suitable for use as aggregrate in the dam's concrete. Rhodes also referred to the dam then being designed by Eastwood as having "a plan of crest showing an obtuse angle,open upstream, of about 165 degrees" with "both sides of this angle (being) straight lines." This is the form of the present Littlerock Dam and and is the first specific reference to the dam design that was ultimately built.[17] On September 30, Eastwood indicated that the design drawings would be finished "in a day or so" and they were dated October 2, 1919.[18] During the next three years these plans comprised the focus of all debate concerning the suitability of the dam and aside from alterations in details, would constitute the final plans.

During October the plans were delivered to the Railroad Commission and information concerning the design was provided to two contractors, Bent Brothers and W.A. Kraner Inc., who were interested in the job.[19] On October 25, 1919, the Railroad Commission indicated they had approved Eastwood's latest design but this did not mean that construction of the dam could begin immediately.[20] As expressed in the Railroad Commission's decision the previous spring, the State Engineer was still required to approve the "details" of the dam design. On Novemoer 13, C.H. Kromer of the State Engineers office, C.H. Loveland, hydraulic engineer with the Railroad Commission, and M.R. Ready, assistant engineer with the Railroad Commission met to discuss Eastwood's latest design. Very little was actually decided at the meeting except that maximum allowable stresses would have to be specified and that the design should then be formally checked to make sure that these stresses were not exceeded. Basically, Eastwood had designed the dam so that the buttresses and arches would be subjected to 300 pounds per square inch (PSI) compressive stress and that the shearing stresses in the buttresses would be 118 PSI.[21] In January, 1920 C.H. Kromer filed an internal memo to McClure that indicated his belief that the intensity of stresses in the dam would be too high.[22] Following this, it appears that acitivity related to approval of the design was almost nonexistant during the first part of 1920.

Sometime during the Winter or early Spring of 1920 a decision was made by the Littlerock and Palmdale Irrigation Districts that they would again become officially involved with the Palmdale Water Company in building the Littlerock Dam. This meant that, in line with the 1917 dam safety law, the State Engineer would have to explicitly approve the Littlerock Dam design. The State Railroad Commission would still be involved in the matter through the Palmdale Water

Company but the State Engineer's Office now clearly exercised the most power in the design approval process.[23] In May 1920 C.H. Kromer and M.E. Ready met again to discuss the dam. Discussion focused on the stresses in the dam with Kromer expressing his thought that the shearing stress should be limited to half of the 118 PSI that comprised the basis of Eastwood's design of October 2, 1919.[24]

On May 27 Kromer took Eastwood's plans to W.L. Huber,the same consulting engineer who had strongly criticized Eastwood's "Radial Cone" design the year before. Huber indicated his dislike of certain features of the design, such as the angle in the dam, but stated that though "the stresses in the structure are somewhat higher than I would myself make them in making a design, and while probably a little beyond the limits of conservative engineering they cannot be classed as actually unsafe."[25] H.H. Wadsworth, another private engineer consulted by McClure, also indicated his belief that the shearing stresses in Eastwood's design were too great. In spite of a spirited defense by Burt Cole, engineer for the Palmdale Irrigation District, in which Cole referred McClure to a great many standards and structures that indicated the allowable stresses in the Littlerock Dam to be most reasonable, McClure stated that "until corrections are made" then "the plans cannot be approved."[26]

With this turn of events, the prospects of constructing of the Littlerock Dam again appeared to be bleak. Eastwood met directly with Wadsworth to counter his criticisms regarding the nature and intensity of shearing stresses in the design. However, he confessed that Wadsworth appeared unable to grasp the true nature of

the design and that results of the meeting were inconclusive. In a letter to Cole, Eastwood expressed his frustration at the objections raised by Wadsworth and Huber by referring to them as experts who "do not know the first thing about the matters they discuss so learnedly for cash and future favors..." and that "if we succeed in showing that [these engineers are] all wrong, there are always others to step in to try to down a competitor in business."[27] Eastwood's blunt assessment of the situation certainly would have done little to endear him to McClure, and perhaps his somewhat arrogant atitude did not help the whole situation. Regardless, one must have sympathy for him given that it was well over two years since he had begun work on designing a dam for the farmers of the South Antelope Valley and he appeared to be no closer to getting a dam built than he had in the Summer of 1918.

In August 1920, Donald Barker, President of the Palmdale Water Company, wrote a detailed letter to McClure that reviewed the events up to that time and questioned how the irrigation districts could ever get permission from McClure to build a dam on Little Rock Creek.[28] Barker pointed out that the only type of dam that the irrigation districts could possibly afford was a multiple arch dam. McClure responded to this on August 5 and admitted that "we agree that the type of dam proposed is the only one which may be built within the limits of the two districts."[29] This is a significant admission as it indicates the necessity of the Littlerock and Palmdale Irrigation Districts building a multiple arch dam. In short, there had to be a multiple arch dam on Little Rock Creek or none at all. Unfortunately, McClure did not indicate anyway to resolve the impasse except by reducing the height of the dam, something that would destroy its storage capacity and, consequently its economic viability.

Throughout the Fall of 1920 considerable correspondence was generated by various parties concerning the shearing stresses in the Littlerock Dam as this appeared to comprise the State Engineer's major reservation concerning Eastwood's design.[30] On November 24th, H.H. Wadsworth reported to McClure that, although he still had disagreements with Eastwood, he believed that "shearing stresses of 100 lbs per square inch should not be considered excessive but that to be conservative, "80 or 85" PSI would "produce satisfactory results." This was a considerable change from Wadsworth's position the previous June when he stated that maximum shearing stresses of 60 PSI were "proper."[31] Apparently this had an effect on McClure because on January 4, 1921, he wrote Petchner and indicated he would "consent to 85 pounds per square inch unit stress direct shear in buttresses." Interestingly, he acknowledged that altering the design to even this extent would add so much to the cost of the dam that the financing might require review and/or adjustment.[32]

From February, 1921 till the Spring of 1922 there is no evidence in any available files or archives of activity related to the Littlerock Dam, This information gap of 14 months is strange and prompts a historian to wonder what occurred during this time. By April of 1922 McClure had seemingly changed his mind concerning Eastwood's design and was well on his way to giving it final approval, although this did not occur for another 6 months. Perhaps comments made by Eastwood in a letter to Petchner in October 1920, provide a clue to what transpired between January 1921 and March 1922. In sum, Eastwood refers to the necessity of interesting the Governor of California in the Littlerock Dam situation so that his influence could be used to the benefit of the Littlerock and Palmdale Irrigation Districts.[33]

In April 1922, activity related to the Littlerock Dam was again underway. In correspondence to J.B. Lippincott from the State Engineer's office on April 20, it was disclosed that on January 18, 1921, over 14 months before, McClure had approved Eastwood's design except for "Sheet #5" of the drawings. This sheet was concerned with the "section through the arch ring" and, apparently, the thickness of the arch ring was a major issue that kept the design from being completely approved.[34] Lippincott had been requested by Sheldon and Lancaster Investment Brokers to prepare a report for them on "the feasibility of the proposed irrigation projects of the Littlerock Irrigation District and the Palmdale Irrigation District" in order for them to make a reasoned decision on whether bonds issued to finance construction of the Littlerock Dam would comprise a viable and profitable investment. Obviously, Sheldon and Lancaster believed that construction of the dam in the near future was a real possibility otherwise they would not have arranged with Lippincott for such a study.[35]

Lippencott reported to Sheldon and Lancaster that the Littlerock Dam and irrigation improvements associated with it were "worthy" and that the investment would "result in a valuable public improvement."[36] Lippincott's assessment insured that financing would be available for the project and final approval of the design by McClure appeared imminent. On May 18, 1922 McClure notified the Littlerock and Palmdale Irrigation Districts that he had signed a compromise design drawing for sheet #5 that had been worked out between Mr. Burt Cole and Lippincott.[38] As described in a memo to McClure by his Chief Structural Engineer, this final design was for a dam 158 feet high and with a maximum shearing stress within the buttresses of 109 pounds per square inch (psi).[39]

Apparently, the concerns of the State that shearing stresses exceeding 60 psi were unsafe had disappeared. Likewise the statement made by McClure in 1918 that he would not approve any multiple arch dam design taller than 140 to 150 feet had also been obviated. It appears that McClure chose to consider the height of the dam to be calculated not as the distance from deepest bedrock to the top of the structure, but from the top of the dam to the deepest surface rock at the site. By reinterpreting the height of the dam it was possiole to maintain the fiction that he had not changed his opinion on the maximum allowable height of the dam, when in fact he had. In terms of the minimum thickness of the arch rings he apparently did not change his mind and these were to be built 15 inches thick instead of the 12 inches that Eastwood originally proposed.

With McClure's presumed final approval of the design in hand, efforts to arrange for its construction by the Bent Brothers construction company began in earnest. Bent Brothers reportedly had family ties to the Littlerock area and for this reason they were interested in building the dam for something less than they would normally.[39] On June 26, 1922 Bent Brothers signed a contract with the Palmdale Water Company for the construction of the Littlerock Dam and the next day this contract was approved by the Littlerock and Palmdale Irrigation Districts.[40] This contract did not stipulate a lump sum fixed fee for Bent Brothers' work but instead provided speicific payment for material or activities such as buttress excavation-$2.00 per cubic yard, concrete-$10.93 per cubic yard, or steel reinforcement .0135 per pound. The contract included general specifications that provided a detailed outline of both the nature and quality of the work to be done. In addition, it was specifically stipulated that "during all times the Engineering Department of the State of California shall have the right to examine and inspect said work in progress."

Upon signing this contract Bent Brothers began assembling equipment for the job though they apparently were not able to work on the Littlerock Dam immediately because of other contractual obligations. However, by early August excavation work on the site had begun and it was at this time that the final obstacle impeding construction was encountered. In preparing the drawings for the second dam site Eastwood had worked from a general topographic map of the area. This data was accurate in a general sense but once work began on laying out the dam it became apparent that slight adjustments of the plans had to be made in order to best accommodate the structure to the site. On August 7 these slight adjustments were noted by the State Engineer's representative at the dam and all construction was ordered stopped until the "changed plans were submitted to the State Department of Engineering and Irrigation for approval and action thereon."[41] Although the design was not altered in any substantive way this approval still took almost three months to be obtained.

On November 4, 1922 final approval of the design was given by McClure and, after more than 4 years of discussion and negotiation, construction work was soon to commence [42].

FOOTNOTES

1) Antelope Valley Ledger Gazette, November 30, 1917. page 1.

2) Memorandum of Agreement between John S. Eastwood, Littlerock Creek Irrigation District and Palmdale Water Company, April 15, 1918, Littlerock Creek Irrigation District files.

3) P.M. Norboe to J.S. Eastwood, May 23, 1918, John S. Eastwood Collection, Water Resources Center Archives, Univ. of California, Berkley. (Hereafter reference to this source will be: JSE Collection, WRCA)

4) Sixth Biennial Report of the Department of Engineering, (Sacramento: California State Printing Office, 1918), pages 77-78.

5) W.F. McClure to J.S. Eastwood, December 2, 1918, Department of Water Resources Littlerock Dam File. (Hereafter reference to this source will be: DWR Littlerock Dam File) Research into the DWR Littlerock Dam File was undertaken by the author using copies of the file retained at the Palmdale Water District. Mr. Emil Stipanovich, an attorney for the State of California involved in legal matters pertaining to the Littlerock Dam indicated that the Palmdale Water District's copy of the file should be complete. However, future research may disclose the existance of heretofore unknown documents concerning the Littlerock Dam in the DWR archives.

6) W.F. McClure to Burt Cole, November 26, 1918 JSE Collection, WRCA.

7) J.S. Eastwood to Burt Cole, November 27, 1918, JSE Collection, WRCA.

8) William Petchner to W. F. McClure, December 3, 1918, DWR Littlerock Dam File.

9) W. F. McClure to Irving Martin, January 13, 1919, DWR Littlerock Dam File.

10) H. W. Brundige to W. F. McClure, March 28, 1919, DWR Littlerock Dam File.

11) W. F. McClure to H. W. Brundige, March 29, 1919, DWR Littlerock Dam File.

12) Memorandum on Plans for Littlerock Dam draft April 19, 1919, DWR Littlerock Dam File; and W. L. Huber to W. F. McClure, May 24, 1919 DWR Littlerock Dam File.

13) W. L. Huber to W. F. McClure, June 21, 1919, DWR Littlerock Dam File.

14) W. C. Petchner to W. F. McClure, June 14, 1919, J. B. Lippincott Collection,
Water Resources Center Archives (hereafter reference to this source will be: JBL Collection, WRCA).

15) J. S. Eastwood to Burt Cole, July 10, 1919, JSE Collection, WRCA.

16) J. S. Eastwood to William Petchner, August 16, 1919, JSE Collection, WRCA. Reference to the construction of two dams on Little Rock Creek appears as late as December 9, 1921, when the Antelope Valley Ledger Gazette indicated that work was "to start soon on two large dams."

17) C. I. Rhodes to C. H. Loveland, September 17, 1919, OWR Littlerock Dam File.

18) J. S. Eastwood to William Petchner, September 30, 1919, JSE Collection, WRCA.

19) J. S. Eastwood to Bent Brothers, October 17, 1919, JSE Collection, WRCA; and C. H. Kromer to William Petchner, October 2, 1919, JSE Collection, WRCA; and J. S. Eastwood to William Petchner, October 25, 1919, JSE Collection, WRCA.

20) W. R. Williams to Palmdale Water Company, October 24, 1919, DRW Littlerock Dam File.

21) Memo by C. H. Kromer concerning conference with C. H. Loveland and M. E. Ready on November 13, 1919, DWR Littlerock Dam File.

22) Memo by C. H. Kromer concerning his recommendations on the plans for the Littlerock Dam, January 1920.

23) W.R. Williams to Palmdale Water Company, May 3, 1920, JSE Collection, WRCA; and Palmdale Water Company to Railroad Commission of the State of California, May 18, 1920, JSE Collection, WRCA. Perhaps as a reflection of the changed role that the Littlerock and Palmdale Irrigation Oistrict would play in the construction of the Littlerock Dam Eastwood signed a new contract with the Palmdale Water Company on March 1, 1920. Contract in Littlerock Creek Irrigation Oistrict Files.

24) Memo by C.H. Kromer concerning his conference with M.E. Ready on May 20, 1920. OWR Littlerock Dam File.

25) W. L. Huber to W.F. McClure, May 28, 1920, DWR Littlerock Dam File.

26) H.H. Wadsworth to W.F. McClure, June 23, 1920; Burt Cole to Donald Barker, June 18, 1920; W.F. McClure to Burt Cole, June 24, 1920; DWR Littlerock Dam File.

27) John S. Eastwood to Burt Cole, July 10, 1920, JSE Collection, WRCA.

28) Donald Barker to W.F. McClure, August 2, 1920, DWR Littlerock Dam File.

29) W.F. McClure to Donald Barker, August 5, 1920, OWR Littlerock Dam File.

30) See John S. Eastwood to William Petchner, November 6, 1920;s John S. Eastwood to Burt Cole, December 7, 1920; John S. Eastwood to Burt Cole, December 8, 1920; John S. Eastwood to Burt Cole, December 20, 1920; in JSE Collection, WRCA. Also see C.H. Kromer to W.F. McClure, October 1, 1920; John S. Eastwood to W.F. McClure, November 9, 1920; Memo concerning response to Eastwood letter of November 9, 1920 to McClure; Notes by C.H. Kromer concerning response to Burt Cole's letter of November 10, 1920 to W.F. McClure; C.H. Kromer to W.F. McClure, November 19, 1920; all in DWR Littlerock Dam File.

31) H.H. Wadsworth to W.F. McClure, November 24, 1920, DWR Littlerock Dam File.

32) W.F. McClure to W.C. Petchner, January 4, 1921, DWR Littlerock Dam File.

33) J.S. Eastwood to W.C. Petchner, October 16, 1930, JSE Collection, WRCA.

34) Paul Bailey to J.B. Lippincott, April 20, 1922, JBL Collection, WRCA.

35) J.B. Lippincott to Sheldon and Lancaster Investment Brokers, April 15, 1922, JBL Collection, WRCA.

36) Ibid.

37) W.F. McClure to Littlerock and Palmdale Irrigation Districts, May 18, 1922, Littlerock Creek Irrigation District Files.

38) Memo from Chief Structural Engineer to W.F. McClure, May 16, 1922, DWR Littlerock Dam File.

39) Southwest Builder and Contractor, Aug. 22, 1924, page 44.

40) Contract between Bent Brothers and the Palmdale Water Company, June 26, 1922, JBL collection, WRCA.

41) Memo from A.F. McConnell to W.F. McClure, August 7, 1922, DWR Littlerock Dam File.

42) Copies of design drawings for the Littlerock Dam with W.F. McClure's signature approving them dated Nov. 4, 1922 are located in the files of the Littlerock Creek Irrigation District.

Construction of the Dam

Following final approval of the design by State Engineer McClure on November 4, 1922, work on the Littlerock Dam began immediately. That same day it was reported that "mixer plant equipment and crusher" had already been installed and that "spouting equipment" for pouring concrete was on the site.[1] Excavation for some of the buttress foundations was underway and Bent Brothers hoped to begin pouring some buttresses before mid-November, though this proved to be somewhat optomistic. On November 25 it was reported that many buttress foundations had been cleared down to "solid material" and that wooden forms for the concrete had begun to be erected.[2] Construction on the dam generally preceded from the spillway side (west) towards the east where the deepest part of the streambed lay.

Despite considerable rain and flooding during December 1922, construction of the dam continued and on December 6 concrete was poured for the first buttress (No. 6). The rain hampered excavation activities as it required pumping to clear out some of the "pits." However, it was a manageable problem. From the beginning of the concrete "pours" for the dam, test specimens were made and analyzed by R.G. Osborne's laboratories in Los Angeles and later by Smith, Emery and Company of San Francisco.[3] These tests were made throughout the dam's construction and insured that no inferior concrete was allowed to be used in the structure.

For the next 15 months Bent Brothers continued working on the dam and throughout that time a representative of the State Engineers' Office visited the dam every three to four weeks and filed memos describing construction activities on the site. These memos still exist as part of the California Department of Water Resource's files on the Littlerock Dam and comprise perhaps the best evidence that the State of California was closely involved in the dam's construction. In fact, the memos indicate that the condition of all buttress foundations had to be approved by the State's representative before concrete could be poured on them and that, on at least one occasion, the State Engineer himself sent a letter specifically approving concrete to be poured on a buttress foundation.[4]

Construction of the Littlerock Dam involved three basic activities: 1) excavation; 2) construction of wooden form works in which tne steel reinforcement was positioned and 3) mixing and pouring of the concrete.[5] Each of these activities had to be carried out sequentially. However, it was possible for different aspects of the construction process to be carried out at this same time at different parts of the dam. For example, concrete could be poured for one buttress while form work was under construction three buttresses away and while excavation continued in the stream bed of Little Rock Creek Canyon.

Because the dam had to rest directly on bedrock it was critical that excavation for each buttress and arch ring be taken completely down to bedrock and that all loose rock, dirt, etc. be removed. Most excavation was done by two Erie shovels and the rock and sand were removed by dump cars attached by cables to hoists. At times, boulders as large as 15 ft. in diameter were encountered and these were

removed only after being broken up with explosives. To prevent the Little Rock Creek's runoff from impeding the excavation process, a wooden flume was built to carry the water flow through the dam site and empty it into the creek bed downstream. Usually this flume could handle the entire flow, but there were some freshets that exceeded the capacity of the flume and disrupted construction. The seepage of water into the excavation trenches was also a problem and pumps were used to remove the collected moisture.

Approximately 60,000 cubic yards of earth and rock were excavated from the site, considerably more than had been initially estimated. This was primarily due to the greath depth of bedrock in the stream bed channel. It had been initially thought that bedrock lay only about 20 feet below the surface, when in reality in places was closer to 50 or 60 feet below the surface. This problem of reaching bedrock in the stream bed was the most time consuming and unexpected difficulty Bent Brothers encountered during the job. Though it necessitated extra work, it did not prevent the dam from being completed in a first class manner.

Once the bedrock foundations had been cleared then construction of the wooden form work could begin. Many of the workers at the site were carpenters as the building of the forms was the most labor intensive aspect of the construction process. Special care had to be taken in building the forms because their configuration and arrangement determined the ultimate shape of the concrete. Eastwood's design was sophisticated in the sense that the thickness of the buttresses and arches varied depending upon their elevation in the dam. The

forms had to be built in a manner that would accurately accommodate these changes in dimension. "Travellers" that allowed various parts of the form work to be moved and reused following a concrete "pour" comprised an important part of the field equipment and helped accelerate the pace of construction.

Once the formwork for a buttress or arch ring had been built it was necessary for the steel reinforcing to be placed within it prior to pouring the concrete. Not surprisingly, different parts of the dam contain different amounts of reinforcing. In the arch rings there is a continuous "mesh" that provides reinforcement both laterally as well as up and down, while in the buttresses the reinforcement is concentrated at their upstream edges. Reinforcing also runs the entire length of the dam through the strut-tie beams.

The actual pouring of the concrete was accomplished by a large apparatus that delivered the mixed concrete to the forms through a long chute. First, material excavated from the buttress trenches was crushed into aggregate for the concrete by rotary crushers located just downstream from the dam site. This aggregate was then mixed with the cement in one of two one-half cubic yard concrete mixers. During most of the dam's construction, these mixers produced 90 cubic yards of concrete an hour. The mixing of the concrete was the simple part; the difficulty lay in delivering it to the various parts of the structure quickly and efficiently.

Bent Brothers decided that the most expeditious means of transporting concrete to all parts of the dam was via chutes connected to a tall wooden central tower and supported by two wooden subsidiary towers. Basically, the freshly mixed concrete was hoisted up the central tower in one cubic yard buckets and then placed into chutes that were primarily supported by the two small towers. The construction crew made sure that the chutes were positioned so that they would deliver the concrete to the correct forms. The 16 inch diameter chutes were carefully counter balanced so that the concrete flowing through them would not disrupt their equilibrium and perhaps cause the concrete to uselessly fall on the ground. Because the structure is over 700 feet long and has a maximum width of over 200 feet, the operation of this chuting system was a critically important aspect of the dams construction.

Following a "pour" the concrete was allowed to "set" for several days, whereupon the forms were removed and preparations begun for constructing the next set of forms above the previous "pour." The wooden forms were reused as much as possible in order to save money. Before the next "pour" took place, care was taken to insure that no loose rock or debris was accidently left on top of the concrete surface being poured on as this would adversely affect the integrity of the structure. The concrete was poured in "lifts" of approximately 5 to 6 feet so, consequently, many "pours" were required for each arch and buttress.

As mentioned earlier, the most serious problem encountered during construction occurred in the excavation of the streambed. Initially it had been estimated that bedrock lay approximately 15-20 feet below the surface in the streambed out this turned out to be far too optimistic. In fact, one part of the dam required an excavation of 63 feet in order for bedrock to be reached.[6] Excavation of the buttress foundations to bedrock was absolutely mandatory in order to insure the dam's stability and adherance to this requirement was scrupuluosly maintained. This unexpected excavation work affected Bent Brothers operation in two ways: 1) it required them to spend more time than they anticipated on excavation and this delayed the entire construction process; and 2) it meant that far more rock was excavated than was necessary to be used as aggregate for the concrete. Bent Brother's unit prices for the construction work had been predicated on the assumption that all excavated rock would be used for aggregate and, in order to come up with a "rock bottom" price for the dam work, they did not include such additional excavation expenses in their estimations. However, when more rock was excavated than had originally been planned, Bent Brothers had to absorb this extra cost. Fortunately this was not so much that the project's financial stability was seriously jeopardized but it did cause some concern during the Spring of 1923.

The citizens of the South Antelope Valley maintained close interest in the dam and the Palmdale Reporter kept reader's apprised of construction progress. Numerous articles appeared in the Reporter related to the dam and, aside from the fact that they often were too optimistic in predicting the date of the structure's completion, they reflect generally accurate knowledge concerning

activities at the dam site.[7] The Reporter was particularly interested in visits made to the dam site by officials and dignitaries. On October 23, 1923 they reported that State Engineer McClure had recently visited the dam and "pronounced it the best piece of concrete dam work he had ever seen" and that "he was mighty well satisfied with the progress of the work thus far on the big project."[8] Similarly, on January 19, 1924 the Reporter indicated that a group of engineers, including a "Mr. Nessky, an eminient engineer from Holland" had visited the dam. Mr. Nessky was apparently most impressed by the structure as he reportedly stated "it (to be) the finest and strongest dam he had ever inspected" He was also reported as saying that he considered "Mr. Eastwood, its designer, to be twenty years ahead of his time in the matter of concrete dams."[9]

Work on the dam continued throughout 1923 and by the end of the year the structure was approaching completion. On March 26, 1924 Mr. E.C. Eaton of the State Engineer's Office reported that only 345 cubic yards of concrete remained to be poured for the dam and that a substantial portion of the workers at the site were involved in "wrecking" or dissembling the plant.[10] During the next several weeks, final work on the dam was undertaken and Bent Brothers removed their construction equipment. By late May it was reported that the dam was "completed" and Mr. Eaton reported that "a surface examination indicates the concrete work to be excellent."[11] This assessment, in conjunction with their repeated inspections of the dam while it was under construction, provide compelling evidence that the State Engineer's Office approved of both the design and the actual construction of the dam in accordance with this design. Acknowledgement of this approval was formalized in a letter from State Engineer

McClure to the Boards of Directors of the Littlerock and Palmdale Irrigation Districts dated June 5, 1924 in which he clearly states "Please note that as of date June 1, 1924 your Little Rock Creek Dam is pronounced complete, and is accepted as complete by this department."[12] If any further evidence is needed to affirm the State Engineer's approval of the Littlerock Dam one need look no further than the Report of the Division of Engineering and Irrigation, a Subdivision of the Department of Public Works of the State of California dated November 30, 1924. This report includes a photograph of the Littlerock Dam as its frontispiece that is captioned "Erection authorized and construction supervised by the Division of Engineering and Irrigation.[13]

The final cost of constructing the Littlerock Dam came to $467,105.18.[18] This sum includes all fees and expenses directly related to the construction of the dam proper but it does not incorporate the cost of ditches, flumes, gateworks, etc. that were built as part of the new system used to transport water from the dam to the Harold Reservoir near Palmdale.

Ironically, once the dam was completed it still took almost two years for the dam to demonstrate its ability to hold back the waters of Little Rock Creek. Throughout the rest of 1924 and all of 1925 a drought descended upon the Antelope Valley and no appreciable precipitation accumulated in the creek or behind the dam. It wasn't until early April 1926 that heavy rains over a period of several days filled the dam and the the spillway was activated for the first time.[15] Finally after 8 years of effort the waters of Little Rock Creek were being impounded to allow for more extensive and regulated development of the South Antelope Valley.

Footnotes

1. Memo from E.C. Easton to W.F. McClure, November 6, 1922, DWR Littlerock Dam File.

2. Memo from E.C. Easton to W.F. McClure, November 27, 1922, DWR Littlerock Dam File.

3. Memo from E.C. Eaton to W.F. McClure, December 24, 1922, DWR Littlerock Dam File.

4. Memo from E.C. Eaton to W.F. McClure, January 20, 1923, and W.F. McClure to W.C. Petchner, May 21, 1923, DWR Littlerock Dam File.

5. "Highest Multiple Arch Dam in the World is Constructed Under Great Dificulties," Southwest Builder and Contractor, August 22, 1924, pages 44-46. Note: The Littlerock Dam was the tallest reinforced concrete multiple arch dam in the world when it was built. The Tirso Dam in Italy being built at the same time was taller but it utilized buttresses comprised of stone masonry. All material relating to the techniques of constructing the Littlerock Dam has been taken from the article in the Southwest Builder and Contractor.

6. Southwest Builder and Contractor, August 22, 1924, page 44.

7. Microfilm copies of the Palmdale Reporter are preserved at the Los Angeles County Library in Lancaster. These microfilm copies begin on July 7, 1923, though the newspaper itself may have been printed prior to that time. Articles related to the dam appear in the July 7, 1923; August 18, 1923; August 25, 1923; September 8, 1923; October 6, 1923; October 23, 1923; January 19, 1924; June 28, 1924; and July 19, 1924 editions of the paper.

8. Palmdale Reporter, October 23, 1923, page 1.

9. Palmdale Reporter, January 19, 1924, page 1.

10. Memo from E.C. Eaton to W.F. McClure, March 26, 1924, DWR Littlerock Dam File.

11. Memo from E.C. Eaton to W.F. McClure, May 31, 1924, DWR Littlerock Dam File.

12. W.F. McClure to the Board of Directors, Littlerock Creek Irrigation District and the Board of Directors, Palmdale Irrigation Districts; June 5, 1924; This letter is retained in the files of the Littlerock Creek Irrigation District Files although, strangely it does not appear to remain in the Department of Water Resources file on the Littlerock Creek Dam. It is important to note that at the time of the dam's completion and before any water had been stored behind it, numerous "hairline" cracks were reported to be visible in the Littlerock Dam. The existance and location of many of these cracks were noted by Mr. E.C. Eaton to State Engineer McClure in his memos to him concerning the dam's construction. The existance of these minor cracks is noted in Edward Wegmann's book The Design and Construction of Dams

(New York; John Wiley and Sons, 1927) where, on page 490 it states "The arches and buttresses (of the Littlerock Dam) are reinforced. In spite of this, there developed small cracks in some of the arches as well as in some of the buttresses. These cracks showed up during the construction of the dam and before any water had accumulated in the reservoir. It is evident, therefore, that the cracks resulted from shrinkage and temperature, and were not due to load conditions."

13. Report of the Division of Engineering and Irrigation, a Subdivision of the Department of Public Works, (Sacramento: California State Printing Office, 1925) page 5.

14. Palmdale Reporter, June 28, 1924, page 1.

15. Western Construction News, April 25, 1926, page 36.

Conclusion

For more than 50 years since the Littlerock Dam reservoir was first filled the structure has provided unfailing service to the citizens of Littlerock, Palmdale and the South Antelope Valley. Though this historical report has focused on the origins and construction of the dam it is worth noting that it survived the unprecedented floods of early March 1938 in a manner that irrevocably demonstrated the strength of Eastwood's design and the integrity of the Bent Brother's concrete work. Because the dam's original spillway became clogged with debris during this storm, the reservoir poured over, or "overtopped," the entire length of the dam for several hours and, aside from damage to the spillway, the structure was unharmed. Similarly, during the famous Tehachapi earthquake of 1952, when great damage was inflicted upon the Antelope Valley, the dam withstood the shock unimpaired.

Beyond consideration of the Littlerock Dam as an historic engineering structure it is significant within the context of California's water resources development and the long standing conflict between large land owning interests and farmers who banded together to form irrigation districts. In his recent book Aqueduct Empire, Mr. Irwin Cooper discusses the intense battle that took place between large land owners and irrigation district interests over the constitutionality of the 1887 Wright Act and the irrigation districts it allowed to be formed.[1] In fact, the opposition to these irrigation districts was so great that it was not until November 16, 1896 that the United States Supreme Court ruled in the case of Fallbrook Irrigation District vs. Bradley, 164 U.S. 112 that irrigation districts

organized under the Wright Act (as was the Littlerock Irrigation District) were constitutional.[2] Apparently, the idea of farmers joining together to undertake communal water development projects was considered undesirable by some portion of California's population. Fortunately for the farmers of Littlerock, the U.S. Supreme Court recognized the value and constitutionality of irrigation districts and such developments were allowed to continue.

When one considers the efforts to outlaw California's irrigation districts in the 1890's, it is easier to comprehend why the Littlerock and Palmdale Irrigation Districts might have encountered resistance to their efforts to construct a dam on Little Rock Creek and thus more fully utilize its water resources. The same interests that were opposed to irrigation districts in the 1890's had by no means disappeared by the 1920's and, in this context, it is perhaps easier to understand why gaining state approval of the Littlerock Dam design was such a time consuming and arduous task. Once a dam was built on Little Rock Creek then the water run-off from 64 square miles of the San Gabriel Mountains would be exclusively controlled by the two irrigation districts for as long as the dam was allowed to operate. Given the great lengths that Los Angeles, and other Southern California communities, have gone to import water from the Owens Valley, the Colorado River, and the Feather River it is remarkable that the Little Rock Creek watershed is still controlled by local districts whose origins date to the 1890s.

As even the California State Engineer conceded at the time, it would have been impossible for the Littlerock and Palmdale Irrigation Districts to build any type of dam other than a multiple arch dam, as all others would have been too expensive for the farmers to afford. Consequently, in a rather unique manner, John S. Eastwood's engineering vision has provided the South Antelope Valley with an economic resource of enormous value for more than 50 years. Eastwood's perseverance in advocating the economy and safety of mulitple arch dam designs did nothing to endear him to those persons or groups who had no interest in the growth of irrigation districts and, in part, this may help to explain his relative anonymity in histories concerned with engineering in the West.

The technology of mulitple arch dams is one that has been used throughout the world during the 20th century, but various economic and technological factors worked to prevent its widespread usage. Though in the teens and 1920's it was among the least expensive types of dams to construct, the extensive amount of labor required to build the wooden forms for the concrete ultimately cost too much money for multiple arch dams to remain competitive. The development of huge earth moving equipment helped make earth-fill dams economically attractive, for example, and multiple arch dam technology has now largely oecome passe. Regardless, it is important to note that there has never been a multiple arch dam in America that has suddenly failed in anyway and resulted in loss of life or property.

In conclusion it is hoped that this report will serve to increase the general public's appreciation of the Littlerock Dam and increase their understanding of its history. It documents the State of California's extensive involvement in approving the design and construction of the dam and will hopefully be of value to persons who wish to learn more about why and how the Littlerock Dam came to be built.

Footnotes

1. Irwin Cooper, Aqueduct Empire, (Glendale, California: Arthur H. Clarke Company, 1968), pp. 45-47.

2. Frank Adams, Irrigation in California 1887-1915, State of California Department of Engineering Bulletin No. 2, (California State Printing Office, 1916), pages 46-47.

LITTLE ROCK CREEK DAM
(Little Rock Dam) (Palmdale Dam)
Little Rock Creek
Littlerock Vicinity
Los Angeles County
California

HAER No. CA-8

ADDENDUM TO
LITTLE ROCK DAM
Little Rock Creek
Littlerock Vicinity
Los Angeles County
California

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

HISTORIC AMERICAN ENGINEERING RECORD
National Park Service
Western Region
Department of the Interior
San Francisco, California 94107

HISTORIC AMERICAN ENGINEERING RECORD
LITTLE ROCK CREEK DAM (Littlerock Dam, Palmdale Dam)

This report is an addendum to a 53-page report prepared in 1981 and previously transmitted to the Library of Congress.

Location:

In the foothills of the San Gabriel Mountains on the Little Rock Creek, southwest of the town of Littlerock, Los Angeles County, California.

UTM Coordinates: 11/406200/3816300

Date of Construction:

1922-24 [Designed in 1919]

The first reference to a reinforced concrete multiple arch dam for the site is 1915, with two known preliminary designs in 1918.

Present Owners:

Littlerock Irrigation District and Palmdale Water District, Palmdale, California

Present Use:

The Little Rock Creek Dam im-pounds the runoff of Little Rock Creek. Stored water irrigates the orchards surrounding the communities of Littlerock to the northeast and Palmdale to the northwest. The dam also provides a water supply for Palmdale Lake (Harold Reservoir).

Significance:

When constructed in 1922-24, the Little Rock Creek Dam was the second highest multiple arch dam in the world, second only to that built in Tirso, Italy, at the same time. The Little Rock Creek Dam was the highest reinforced concrete multiple arch dam of the period, with

the Tirso Dam of masonry-reinforced concrete construction. Sited adjacent to the very active San Andreas faultline, the dam is a superlative example of the innovative and artistic design work of internationally-acknowledged engineer John S. Eastwood. The Little Rock Creek Dam has provided water for the South Antelope Valley for nearly 70 years. Little Rock Creek Dam was listed on the National Register of Historic Places in 1976.

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PART I. HISTORICAL INFORMATION

Irrigation and the Agricultural Development of the South Antelope Valley, 1886-1940

Agricultural development of the South Antelope Valley in the Mohave Desert began in the middle 1870s, with the completion of the Los Angeles to San Francisco route of the Southern Pacific Railroad on September 6, 1876. By 1880 the rail corridor serviced four newly-platted communities in the Soledad Township, Lancaster, Alpine, Acton and Newhall. Settlement existed on paper only, with two Newhall farmers tilling the land. (Thompson & West: 1880, pp. 73-76, 103, 190.) The Southern Pacific promoted colonization of the land adjacent to its route through the Antelope Valley. Immigrants from Lancaster, Pennsylvania, had founded Lancaster in 1877. In addition to the platting of Alpine, Acton and Newhall by 1880, the Scottish Wicks Colony established itself in the area in 1883, the English Kingsburg Colony in 1885 and the German Lutheran Palmenthal in 1886. Named for the Joshua Tree, popularly called the Yucca Palm, Palemthal became Palmdale in 1890. (Dunkerly: 1940, pp. 30-31; Gudde: 1962, pp. 171.) During most of the 1880s, sporadic ranching dominated the unfolding local economy, with the naturally-occurring bunch grass permitting winter and spring grazing. With an annual rainfall of about eight inches, the arid area should have presented itself as one settlers would approach with caution. Coupled with the dry climate, however, were cyclical wet and dry periods. During the Southern Califomia boom of the late 1880s, real estate promoters captured the settlers' collective imagination through their insistence that the underground water table and consistent winter rains made wheat farming not only stable, but highly profitable. And from the middle 1880s through the middle 1890s wet year after wet year graced the Palmdale area, only seeming to confirm the promoters' hyperbole. (Kyle: 1990, pp. 47-49.)

In November 1886, the Palmdale Irrigation Company incorporated as the first known waterworks business in the Palmdale vicinity with the intent to acquire land and water, and then rent, lease and sell both as they were developed. As a part of the planned operation, the Palmdale Irrigation Company intended to undertake the building of ditches, flumes, dams, tunnels, canals and reservoirs. The five corporation directors were John J. Jones of Los Angeles, and Victor Fink, Peter Jones, Henry Holst and Jacob Struss, Jr., of Palmdale. Ten thousand shares of stock, at 10 dollars per share, were underwritten, with 40 thousand dollars of stock actually subscribed. Subscribers included the corporation directors and landholders John G. Enke, Gottlieb Elksnat, Henry Fiedemann, John Gerdan and John Spich. John J. Jones, the only non-resident participant in the incorporation, held the majority of the capital stock, with 3295 shares. Peter Jones held the secondmost shares, at 420. (Palmdale Irriagtion Company: 1886.)

The Palmdale Irrigation Company was one of the earliest attempts in California to set up a quasi-public organization to develop, control and regulate water for irrigation. The first

irrigation legislation in the United States predictably occurred in the arid West, in Utah in 1865. California followed by 1872, with its own first irrigation district act. The unsuccessful law was succeeded by another of inoperative type, applicable only to Los Angeles County in 1874. In 1876 and 1878 the Central Valley sponsored two more irrigation district laws, creating the Westside, Turlock and Modesto irrigation districts spread throughout parts of Contra Costa, Alameda, San Joaquin, Stanislaus, Merced, Fresno, and Tulare counties. In 1878 the California State government in Sacramento created the office of the State Engineer. Filled by William Hammond Hall as State Engineer and James Dix Schuyler as Assistant State Engineer, the State Engineer's office focused on issues of publicly-governed irrigation. Drafting highly detailed water maps of most of California, Hall led the irrigation and reclamation campaign for the state, but noted by as early as 1890 that over-irrigation would destroy the soil through a predictable rising water table and alkalinization. In 1886-87 a Modesto lawyer, C.C. Wright, backed landmark irrigation district legislation, a successful turning point in Western American water rights development. The Wright Act provided a vehicle for small farmers to band together in their communities for the purpose of owning and operating irrigation works, inclusive of the right to exercise eminent domain, issue bonds and tax property owners benefiting from the constructed water-controlling devices. In 1889, 1891, 1893, and 1895 the Wright Act was amended to increase its applicability to real-life situations, and in 1897 the Act was rewritten as the Bridgford Act, alternately known as the Irrigation Act of 1897 and the California Irrigation District Act. Notably, the Palmdale Irrigation Company was incorporated before the passage of the March 1887 Wright Act. (Adams: 1916, pp.5-8; Adams: 1929, pp.13-16.)

In 1887-88, 11 public irrigation districts organized in California under the Wright Act. During 1887-89, the Palmdale vicinity enjoyed several wet years and the Palmdale Irrigation Company prospered with several hundred acres irrigated. Plantings included alfalfa and deciduous fruits, with acreage broken up in 10-to-40 acre parcels. Majority owner of the company, John J. Jones, filed a water location record in September 1888 for the diversion of water from Little Rock Creek to Palmdale. The six-foot deep ditch was described as eight-feet wide on the grounds surface, and five-and-one-half-feet wide at its bottom. The Palmdale Irrigation Company diverted 5000 inches of water, miners measurement. (Jones: 1888.) In February 1890 a Wright Act-irrigation district, the Palmdale Irrigation District, challenged the Palmdale Irrigation Company, also proposing to divert water from Little Rock Creek to Palmdale, with storage in a planned reservoir south of Palmdale. Only minimal preliminary work occurred, with the Palmdale Irrigation Company achieving dissolution of the public irrigation district through lower court and supreme court cases. (Adams: 1929, p.268.)

John J. Jones' Palmdale Irrigation Company continued to file papers with the Department of the Interior, including the formal field survey notes and mapping for its ditch and laterals. Filed in 1894, the field survey was required by a public lands irrigation ditch and reservoir right of way law of March 1891. (Palmdale Irrigation Company: 1894-95.) The 1891 law stipulated that if any projected parts of an irrigation ditch remained incomplete after the passage of five

years, then the granted irrigation corridor would be forfeited. (Chandler: 1912, pp.618-19.) The Palmdale Irrigation Company duly noted in its March-April 1894 field survey that its main ditch was already fully constructed, with 5.65 miles transversing public lands and a total ditch length of 6.54 miles. The Palmdale Irrigation Company ditch ran north/northwesterly from a headgate on Little Rock Creek located in the extreme northwestern corner of Section 27, Township 5 North, Range 11 West. The 1886-94 Palmdale Irrigation Company ditch was aligned northwest through Township 5 North, Range 11 West, running northwest across the corner of Section 28, north through the easternmost portion of Section 21, northwest\north through Section 16, north/west through Section 8, northwest across the corner of Section 7, northwest\north through Section 6 and finishing within Township 5 North, Range 12 West, running northwesterly across the corner of Section 1. (Palmdale Irrigation Company: 1894.)

In 1895 yet another Palmdale irrigation company, the South Antelope Valley Irrigation Company, incorporated. The South Antelope Valley Irrigation Company also filed formal field survey notes and a ditch alignment map with the Department of the Interior, as required by the 1891 public lands right of way law. Constructed in 1896 and filed in 1897, their 8.6-mile wooden flume and earthen ditch paralleled the earthen ditch of the Palmdale Irrigation Company during its initial north/northwestwards course, with a headgate about a mile further up Little Rock Creek. The South Antelope Valley Irrigation Company's ditch followed that of the Palmdale Irrigation Company to the south of the earlier company's ditch, diverging substantially in Section 16 on a more directly westerly course toward Palmdale. The five officers of the South Antelope Valley Irrigation Company included Nathan Cole, Jr., President; L.G. Parker, Vice-President; L.T. Cole, Secretary and Treasurer; D.P. Hatch, Director; and Burt Cole, Chief Engineer. Burt Cole surveyed, designed and supervised construction for the company's ditch, inclusive of its wooden flume running the first two miles northwards from the headgate. In addition to a more carefully aligned ditch, with a flume, the South Antelope Irrigation Company also constructed a storage facility, a reservoir immediate to Palmdale, with a 750-foot long outlet tunnel and discharge flume. Known at the turn of the century as the Alpine, Alpine Springs or Harold Reservoir (today, the Palmdale Reservoir), the South Antelope Valley Irrigation Company's water storage facility used a natural basin, and was the first reservoir of any magnitude completed on the Mohave Desert/Antelope Valley side of the Sierra Madres in Southern California. The natural basin had formed as a result of its alignment along the San Andreas earthquake fault. The faultline had geologically created a series of ponds and springs, with water accessible along its edge at very little depth. Once out of the Little Rock Creek canyon and through Sections 21 and 16 of Township 5 North, Range 11 West, the South Antelope Valley Irrigation Company's ditch was directly aligned on the faultline for most of its course to the reservoir. Harold Reservoir was designed for a maximum depth of 34 feet, to impound 5,500 acre-feet of water. The Southern Pacific Los Angeles-to-San Francisco line ran along its northeastern edge, through the rail stop of Harold. The South Antelope Valley Irrigation Company planned to provide water for 10,000 acres northeast of Palmdale, with major initial plantings in olives. A vicinity population of about 200 is estimated at the time of South

Antelope's construction. As a part of the South Antelope Valley planning for the Little Rock Creek watershed, in May-June 1896 civil engineer J.B. Lippincott, a prominent designer of Southern California waterworks and dams during the late 19th and early 20th century, made measurements of the underflow of Little Rock Creek atop the clay of the earthquake fault at the point at which the faultline crossed the creek. The South Antelope Valley irrigation works were stated to have cost $182,000 and were in use in the Spring of 1897. (South Antelope Valley Irrigation Company: 1896 and 1897; U.S.G.S.: 1897, pp.711-15; U.S.G.S.: 1911, p. 34; Lippincott: 1915, p. 1.)

During the late 1880s and early 1890s, Little Rock Creek not only attracted the attention of three irrigation companies based in Palmdale to its near northwest (two of which were successful), but also the attention of three successive organizations established on agricultural lands to the northeast. In 1888 the Alpine Springs Land and Water Company assumed ownership of Section 6, Township 5 North, Range 10 West, and Sections 12 and 13, Township 5 North, Range 11 West. For Section 6 the company platted the town of Tierra Bonita, which evolved into the community of Littlerock but was sometimes mapped as Tierra Bonita until about 1910. (Wright: 1924, p. 100; Wright: 1898; George: 1900; Rueger: 1907.) Officers of the Alpine Springs Land and Water Company included Nathan Cole, Jr., President and H.G. Billings, Secretary. In May 1891 the East Palmdale Water Company commenced appropriating water from Little Rock Creek at the Sycamore Swamp adjacent to the property of T.G. Hodgkins. Located in the northeastern quadrant of Section 22, Township 5 North, Range 11 West, the Sycamore Swamp was also historically known as the Garcia Cienega, and would continue to figure prominently in water rights disputes. The swamp, or springs, resulted from a natural depression formed by the San Andreas fault, and the faultline's distinguishing hard, blue clay along this portion of its course had further caused the formation of a submerged dam at the Garcia-Sycamore Swamp where the San Andreas crosses Little Rock Creek. Possibly the naturally-occurring underground dam was man-enhanced as early as the middle 1880s. Henry Kirke White Bent, the father of next-generation contractors Arthur S. and Stanley Bent, is cited in 1924 as having initiated irrigation development in the Littlerock area "40 years ago." The senior Bent is credited with constructing a submerged dam in the swamp at that time, with water then pumped into private diversion canals. ("Highest Multiple Arch Dam": August 22, 1924, p. 44.) Downstream from the swamp, Little Rock Creek drops away into the deep gravel and sand of the continuing wash.

Hodgkins released rights to his house and land at the swamp, with the East Palmdale Water Company undertaking the construction of a canal on the property "along the line of the ditch as now partially constructed." (East Palmdale Water Company: 1891; Wright: 1898.) The partially constructed ditch is assumed to be that of the Alpine Springs Land and Water Company. In December 1891, the Alpine Springs Land and Water Company Board of Directors met and formalized a petition calling for the organization of the Little Rock Creek Irrigation District. (Alpine Springs Land and Water Company: 1891.) As a part of its petition, the Alpine Springs Land and Water Company included a map of its company ditch diverting water from

Little Rock Creek at the Garcia-Sycamore Swamp. Mapped were the "old ditch" and the "surveyed ditch," with alignment running generally east through Sections 22 and 23, north and then east through Sections 14 and 13, north along the boundary between Range 11 and 10 West to the southern edge of Section 6, Township 5 North, Range 10 West. Section 6 contained the townsite of Littlerock. A final segment of the ditch ran further northeastwards through adjacent Section 5. In addition, a privately owned ditch, Conner's Ditch, also had a headgate on Little Rock Creek, paralleling the course of the company's ditch into Section 6 and the town of Littlerock. The Little Rock Creek Irrigation District became a reality in early 1892, with many of the same leading participants as had been prominent in the Alpine Springs Land and Water Company. Planned land for irrigation was 4,000 acres. (Little Rock Creek Irrigation District: 1892; U.S.G.S.: 1897, pp. 712, 714.)

Thus three major diversions from Little Rock Creek became well-established during the 1886-1896 years. That of the Palmdale Irrigation Company and the South Antelope Valley Irrigation Company, of 1886 and 1896, exited the creek northwestwards to Palmdale at distinct headgates. That of the Alpine Springs Land and Water Company, East Palmdale Water Company, Conner's, and the Little Rock Creek Irrigation District, of 1888-92, exited northeastwards. The three headgates were separated on the waterway by about a mile each, with those of the Palmdale entrepreneurs further up toward the headsource in the Little Rock Creek canyon and that of the Littlerock entrepreneurs set in the waterway at Garcia-Sycamore Swamp. Notably, the second and third irrigation enterprises for the Palmdale-Littlerock area, those of the Alpine Springs Land and Water Company/Littlerock Creek Irrigation District of 1888-92 and those of the South Antelope Valley Irrigation District of 1895-96, contained the same key players, focusing upon the development schemes of the Cole family. Notably too, from the very first years of irrigation development for the Palmdale-Littlerock area, civil engineers Burt Cole and J.B. Lippincott figured significantly in the planning and designing of the watershed's waterworks system, as did the Bent family of local farmers and irrigation contractors. Involvement of the Coles, Bents and Lippincott extended continuously into the 1920s. (U.S.G.S.: 1897, pp. 714-15; U.S.G.S.: 1898, p. 193; U.S.G.S.: 1899, pp. 186-90.) Since all three water rights groups depended on the same river for their business success, it was inevitable that the three would come together to legally define who was entitled to what, an agreement of particular importance in times of minimal water and drought. The predictable agreement followed the South Antelope Valley Irrigation Company's filing for its Federal land right of way corridor, for its ditch and flume, in 1898.

In the agreement, the oldest company, the Palmdale Irrigation Company of 1886 shared equal first rights with the Littlerock Irrigation District, successor to the second oldest company, the Alpine Springs Land and Water Company of 1888. The division of the first 1200 inches of flowing water occurred a mile downstream from the headgate of the South Antelope Valley Irrigation Company on its just-constructed (1896) flume, at the 1886-established headgate location of the Palmdale Irrigation Company. The dividing point was opposite the O'Reilly

house site. Of interest, both the Palmdale Irrigation Company of 1886 and the Alpine Springs Land and Water Company of 1888 established their headgates on Little Rock Creek at pre-existing house sites (O'Reilly and Garcia/Hodgkins). The 1896 ditch system of the South Antelope Valley Irrigation Company had necessitated added irrigation works for the Littlerock Creek Irrigation District, since its own diversion point was below that of the newer company. The logical decision was to extend its ditch system to the point of diversion for the Palmdale Irrigation Company one mile upstream from the swamp and one mile downstream from the South Antelope Valley Irrigation Company's headgates. All water above the first 1200 inches belonged to the South Antelope Valley Irrigation Company and could be distributed as the company saw fit. Another guarantee stated that the South Antelope Valley Irrigation Company, with its controlling headgate furthest upstream on Little Rock Creek, could not diminish the flow of water rising in the Garcia-Sycamore Swamp, that location being the prior headgate of the Alpine Springs Land and Water Company/Littlerock Creek Irrigation District. With respect to the waters of the swamp, the forward-looking irrigators assumed that a submerged dam would someday be constructed therein. Finally, the agreement co-signers addressed the issue of water storage on Little Rock Creek, stipulating that any future reservoir or dam built by the South Antelope Valley Irrigation Company, at South Antelope Valley Irrigation Company's headgate or elsewhere, would be legally predivided. (Little Rock Creek Irrigation District, South Antelope Valley Irrigation Company and Palmdale Irrigation Company: 1898.) Implicit in this most significant 1898 agreement is the mutual understanding between the three early irrigation organizations that the South Antelope Valley Irrigation Company of Palmdale would be taking the lead in future construction of waterworks, and that its 1896-built system had set the stage for a new order of water and land deveopment.

Enveloped in bitter irony, however, the Palmdale-Littlerock area experienced repeated dry years from 1897-98 to 1905. The extended drought meant that very little water was available for the three irrigation organizations. Only the South Antelope Valley Irrigation Company had large-scale storage facilities in place, through its insightful construction of Harold Reservoir at Palmdale, although Littlerock still could depend upon the natural storage at the Garcia-Sycamore Swamp. By 1900 the "water problem" at Little Rock Creek demanded further engineering attention. Consulting engineer F.E. Trask conducted an instrumentation survey at the Garcia-Sycamore Swamp, where J.B. Lippincott had taken measurements in 1896. At that physical juncture of waterway and earthquake faultline it was again presumed that the creek's water could be further developed for piping onto the surrounding lands. During the summer of 1900 a steam pumping plant was built at the swamp a short distance above the naturally-occurring underground dam. The Littlerock Creek Irrigation District operated the pumping plant throughout 1900, but thereafter was able to water its lands through its flume and ditch system. (Trask: 1900; U.S.G.S.: 1911, pp. 34-35.) A man-constructed underground dam, built at the swamp location of the naturally-occurring submerged dam, remained a necessity to create the badly needed, and more reliable, additional water storage. The economics of the extended drought did not permit the irrigation entrepreneurs to carry through with their plans at the turn of the century, but the

idea would recur with ultimate followthrough. By about 1902, the drought had also made water storage at the Harold Reservoir near Palmdale a futile effort. The severe lack of reliable water caused the abandonment of most of the orchards at the west end of the Palmdale colony lands.

In 1904 the South Antelope Valley Irrigation Company entrepreneurs attempted to convert acreage to sugar beets, marketing sugar men for land sale and the construction of a sugar factory at Palmdale. The sale did not go through. (Schuyler: 1910, pp. 7-8.) Also in 1904 the San Gabriel Forest Reserve, of which much of the land surrounding the upper reaches of Little Rock Creek was a part, built a ranger cabin for the Little Rock Creek vicinity. (Robinson: 1991, p. 102.) At some point during the long dry period, the Palmdale Irrigation Company transfered its rights and holdings to the South Antelope Valley Irrigation Company, consolidating operating expenses for Palmdale vicinity water patrons. (Department of the Interior: 1909.) In 1906 the Los Angeles and California Investment Company took control of the South Antelope Valley Irrigation Company through exercise of a stock option, repairing and renovating South Antelope Valley's waterworks system. For the next few years the irrigated lands surrounding Palmdale-Littlerock recovered, with rainfall again successfully channeled and stored. At Harold, sometimes called Alpine Springs, the South Antelope Valley Irrigation Company, under direction of the Los Angeles and Califomia Investment Company, began construction of a hotel and sanitarium in 1908, with a view to further land development. While near Littlerock, approximately 250 acres of pears, 200 acres of apples and 50 acres of almonds were under cultivation on the Little Rock Creek irrigated lands. Later in 1908 the water fortunes reversed themselves again through a massive rain storm that obliterated the headgates and the canyon portion of the wooden flume of the South Antelope Valley Irrigation Company. Without the controlling headgates and diverting flume, the remainder of South Antelope Valley's system, including flume, ditch and reservoir, were once again functionally dry and Palmdale's lands without water. The Los Angeles and California Investment Company let its option lapse and the South Antelope Valley Irrigation Company again became destitute. Littlerock's lands continued to get water from their natural storage point at the Garcia-Sycamore Swamp. In 1910, heavy rainfall again fell upon the region. (U.S.G.S.: 1911, pp. 34-35; Schuyler: 1910, pp. 2, 4, 10-11.)

Throughout the entire 1886 to 1908 period a waterworks theme repeated itself: the need for one or more dams on Little Rock Creek. Both the emergent South Antelope Valley Irrigation Company of Palmdale and the Littlerock Creek Irrigation District of Littlerock needed substantial water storage on the creek itself. Extended drought conditions would make South Antelope Valley's Harold Reservoir useless without water stored at its headgates on the waterway itself. The same conditions would force Littlerock to expend substantial funds, continuously, to pump water from its natural storage at the Garcia-Sycamore Swamp. In addition, the 1908 torrential rains proved that both irrigation organizations had been dependent on a headgate, flume and ditch system that needed physical improvement. In 1910 the Chicago Exploration Company hired James Dix Schuyler of Los Angeles, by then a highly respected

hydraulic engineer and designer of dams, to compile a lengthy report on the remaining components of the South Antelope Valley Irrigation Company's water supply system at Little Rock Creek, with the primary intent of assessing the value of the existing irrigation water supply system once it was augmented by storage facilities. The Chicago Exploration Company, of Chicago, Illinois, had stated its further intentions of buying all of South Antelope Valley's property, inclusive of the waterworks system, 3000 acres of agricultural land and multiple buildings. Engineer Schuyler had previously reviewed the South Antelope Valley irrigation works just after completion in 1896 and again in 1904, likely as a consultant for the American Beet Sugar Company. (Kieffer, Grunsky and Lippincott: 1913, p. 2243.) Schuyler reported in late February that the Harold Reservoir and 6.6 miles of earthen canal were in good condition, but that the segment of the wooden flume in the creek canyon, the diverting dam and intake tunnel at the Harold Reservoir, and bridge carrying the wooden flume over the creek were all but destroyed. As he stated to the Chicago investors, "The whole system has been disused for so many years as to present to the 'tenderfoot', unaccustomed to irrigation, a rather discouraging appearance." (Schuyler: 1910, pp. 8-9.)

Schuyler suggested, not surprisingly, stabilized water storage. The engineer recommended increasing the capacity of Harold Reservoir; immediately building a low regulating reservoir at the headgate of the ditch and flume system in the Little Rock Creek canyon; planning for a high dam further upstream in the canyon to contain a 123-acre reservoir; building an earthen dam at the Garcia-Sycamore Swamp; and, possibly, building a third storage reservoir at one of the naturally-occurring faultline basins between the canyon and Harold Reservoir. In addition, Schuyler noted the needed repairs for the ditch and flume. The immediate suggested regulating reservoir was to be a 60-foot high dam, with 1000-to-1200 acre-feet storage capacity; Harold Reservoir's capacity was to be increased to 7800 acre-feet. The anticipated total storage of 9000 acre-feet was thought to safely irrigate 4000 acres, even in dry years and a fallback conservative need of 6000 acre-feet for the 4000 acres was noted as viable. The intended plantings were Bartlett pears, a valuable specialty crop that had already demonstrated its economic promise in the Palmdale-Littlerock area. Schuyler further remarked that alfalfa would require two times the water as the fruit trees. The future high dam was to be 150 feet in height, and would contain a reservoir of 6500 acre-feet capacity. This second dam directly foreshadowed that ultimately built in its height and breadth, although the as-built site for a Little Rock Creek dam would remain that projected in 1910 for the 60-foot high dam just above the South Antelope Valley headworks. The as-built dam would contain a reservoir extending from the headworks to the diversion of Little Rock Creek at Santiago Canyon. Planned to be 600 feet along its crest and 175 feet along its base, the future high dam would be wedged in the canyon between solid rock abutments. Engineer Burt Cole, the designer of the 1896 South Antelope Valley Irrigation Company's waterworks system, also conducted the survey and planning for the future high dam. Schuyler's projected immediate construction costs were about $200,000. Thirty-five photographs of 1904, 1909 and 1910 site visits accompanied Schuyler's report. (Schuyler: 1910, pp. 16-24.)

Schuyler's recommendations of 1910 lay dormant until March 1912, when Los Angeles consulting engineer T.D. Allin, of the Allin Brothers, undertook the flume rebuilding, reservoir repair and restructuring at South Antelope Valley's headgate. Repair costs dropped from Schuyler's estimated $200,000 to $35,000, with headgate work minimized and the second dam further up the creek, Schuyler's "high dam," recommended for an additional $67,000. By September 1912, costs were reduced even more through relining old flume segments with an asphalt roofing paper rather than fully reconstructing the structure. Lowering costs was a consistent motif. (Allin: March, August, September 1912.) One segment of the flume, however, did mark a real change in construction from the 1896 waterworks. Immediately below the headgate a reinforced concrete box flume replaced former wooden works. Designed and built by the Arthur S. Bent Construction Company of Los Angeles for the Allin Brothers, the reinforced concrete box flume featured top reinforced concrete cross bars to strengthen the box flume in case of an accident or undue pressures at the headgate. The reinforced concrete flume segment was 1590 feet long, measuring seven feet wide by five feet deep. A 60-foot steel-truss replaced a Howe truss bridge carrying the flume across Little Rock Creek. Work began in December 1912, and was completed in May 1913. (Bent: 1912, 1913; Palmdale Land Company: 1914; Lippincott: 1915, p. 2.) The Palmdale Water Company, the company formed to purchase South Antelope Valley's 3000 acres in the Palmdale vicinity with their associated waterworks, directed the 1912 improvements, formally buying their predecessor through the Merchants Bank and Trust Company of Los Angeles just prior to construction in late October. The Palmdale Water Company noted its intentions to build a large-scale dam on Little Rock Creek at a future date. (South Antelope Valley Irrigation Company: 1912; Adams: 1929, pp.268-71; Palmdale Water Company: 1915.)

The year 1912 also was one of major changes for the Littlerock Creek Irrigation District and its associated lands and waterworks. Paralleling the formation of the Palmdale Water Company and exactly coincident with Allin's survey of the South Antelope Valley irrigation system, the Little Rock Power & Water Company incorporated in March 1912, with a capital stock of $500,000. The power company's President, S.P. Jewett, was an irrigation engineer himself, with the company's engineer, W.R. Wenk of Los Angeles. The Little Rock Power & Water Company filed for a final water power permit in San Francisco in September 1912. The company proposed a dam site and reservoir six-to-seven miles up into Little Rock Creek Canyon, about five miles above the headgate of the Palmdale Water Company (previously, the headgate of the South Antelope Valley Irrigation Company) in the Angeles National Forest. Connected to the dam by a nearly eight-mile long pipeline, the company's power house site was the old pumping station site of 1900 at the Garcia-Sycamore Swamp two miles southwest of Littlerock. The Little Rock Power & Water Company proposed building a transmission line across the Mohave Desert to the mines at Randsburg, 60 miles distant. Other power lines would supply irrigation pumping stations for Antelope Valley irrigation districts. Presumably the company's chosen dam site is the same one selected by engineers Cole and Schuyler in 1910 for the then-described "high dam." By 1912 the height of the dam had been reduced from 150 feet to 110 feet in the

plans of the Little Rock Power & Water Company, but parameters of breadth remained approximately the same. Storage capacity was reduced from 6500 acre-feet to 1435 acre-feet for both the power corporation's planned dam and for Allin's "second dam farther up the creek." Presumably, Allin's dam and that of the Little Rock Power & Water Company were one and the same, a designed, but uncredited, structure of 110-foot height, 650-foot length, six feet wide on top and 70 feet thick at the bottom. (Little Rock Power & Water Company: 1912; Allin: March 1912.) Little Rock Power & Water Company's plans for a dam on Little Rock Creek also introduced government regulation for the first time: the California Public Utilities Act of 1911 required the Railroad Commission to review and approve the dam as a public utility. (Jackson: 1986, p. 48.)

The 1912 engineering surveys of the Little Rock Creek canyon and watershed by both Palmdale and Littlerock entrepreneurs rekindled the late 19th century local competition for developing the water rights. The situation appears to have been somewhat of a race, with each town backed by Los Angeles corporate interests, and each aware of the other's efforts but unenlightened as to their full meaning. Representatives for the Little Rock Power & Water Company noted in September 1912 that a new company, the Little Rock Fruitland Company, had posted notice at the old headgate of the South Antelope Valley Irrigation Company. The Little Rock Fruitland Company became a subsidiary of the Palmdale Water Company and appears to have first represented its interests in the canyon. The Little Rock Power & Water Company stated to the Forest Service: "They [Little Rock Fruitland Company] have a man cleaning out the old ditch in places...and tearing down the old flume. As the waters originally claimed for this project have not been used for a number of years, it is improbable that a water right still exists." Nonetheless, the Little Rock Power & Water Company was justifiably worried that a water right would hold up in court, as indeed did the purchased rights of the South Antelope Valley Irrigation Company to the Palmdale Water Company. (Little Rock Power & Water Company: 1912, p. 7.) In an agreement very similar to that of 1898 between the Palmdale Irrigation Company, the South Antelope Valley Irrigation Company and the Littlerock Creek Irrigation District, the simultaneously-incorporated Palmdale Water Company and the Little Rock Power & Water Company of 1912 came to a legal agreement dividing up their respective water rights with the still-existing Littlerock Creek Irrigation District in 1913. By early 1913, the Palmdale Water Company was further subsumed under the umbrella of the Palmdale Land Company. By late 1915, the U.S. Forest Service rejected the application of the Little Rock Power & Water Company for use of Federal lands, noting that its small storage capacity and inaccessible site would make acre-foot costs high for the water. (Palmdale Land Company: January and August 1913; Allin: 1913; Palmdale Water Company: July 20, 1915, pp. 4-5; Lippincott: 1915, p. 6-7.) The Little Rock Power & Water Company, however, continued to exist as a corporation, re-entering the struggles for dam-building on Little Rock Creek in 1921.

While the Palmdale Water Company (Palmdale Land Company) and the Little Rock Power & Water Company undertook improvements in the case of the former, and planned improvements

in the case of the latter, the Littlerock Creek Irrigation District hired a consulting engineer of its own and also planned improvements. In September 1912, again simultaneous with the engineering surveys already underway, the irrigation district hired F.C. Finkle to analyse the potential for water development. Finkle focused on the underground storage basin naturally formed at the Garcia-Sycamore Swamp and cited by Schuyler in 1910 as a good location for a man-enhanced underground dam. (Finkle: 1914.) The Littlerock Creek Irrigation District reorganized itself financially between 1912 and 1916, in fact completing an underground dam at the swamp in 1916. The submerged dam was 360 feet long, 11 feet 8 inches below the ground's surface. (Wright: 1924, p. 97.) In addition the district lined its first three miles of ditch with concrete and effected the water distribution through underground concrete pipe thereafter. Water seepage losses were greatly lessened through moving ahead to concrete pipe, rather than open ditch. The Arthur S. Bent Construction Company, the same contractors who had executed the 1912-13 ditch reconstruction and renovation of the South Antelope Valley Irrigation Company waterworks system from Little Rock Creek to Palmdale for the Palmdale Water Company, contracted to renovate the Little Rock Creek Irrigation District's ditch from the creek to Littlerock. The Bent Brothers undertook the Littlerock work in 1914. (Littlerock Creek Irrigation District: October 1914.) By 1915 the district had between 1400 and 1500 acres cultivated in Barlett pears. (Adams: 1916, pp.91-92.)

During 1913 to 1915, agricultural development, and especially its promotion, dominated the Palmdale and Littlerock vicinity. Midway through this period Europe's entry into World War I created an initial high demand for U.S.-provided food, thus sparking the business of agriculture. Subsidiary companies to the Palmdale Land Company published pamphlets to draw prospective farmers and orchardists to the area. In 1914, the Palmdale Fruitland Company published *Romance and Drama in the Valley of Sunshine: Being a Story of Old Palmdale.* In the pamphlet, the company noted yet another reason for the flush of water and land development activated so precisely in 1912. Not only had the climate frustrated private enterprise in its attempts to build and maintain profitable irrigation works, but land titles were largely tied up in court. The Southern Pacific Railroad had sold much of its land during the late 1880s boom, only to have title claimed by the U.S. government from 1888 until February 1912. Thus, early in 1912, the land could be sold and developed again. Not surprisingly, in March 1912 Los Angeles-backed corporations found themselves keenly interested in land and water in the Palmdale-Littlerock area. The Palmdale Fruitland Company promoted the apple and pear orchards, noting the heavy plantings in 1913. Palmdale could sustain 5000 irrigated acres, Littlerock Creek 3000. Prepared, but uncultivated, land value was placed at between $150 and $200 per acre. The L.A. *Times* advertised "Palmdale Acres" where "Pears Pay Big," in mid-1913, with the same land values. (L.A. *Times*: May 4 and 22, 1913.) By January 1914, in addition to the pamphlet promotional literature, the entrepreneurs behind the Palmdale irrigation project also published an advertising map of the proposed distribution system and its irrigated lands of the future. By this point in the project yet another corporate entity stood behind the scenes, the London Company. The London Company appears to have been hired by the

Palmdale Water Company to take over irrigation works construction from the Allin Brothers, with the intent to complete the two dams. Ernest H. Wilcox served as the London Company's engineer on the Palmdale project. (Allin: 1914.)

By 1915, both the Palmdale Water Company and the Littlerock Creek Irrigation District were working together to build the much-desired dams. Additional land development companies purchased Palmdale-Littlerock property. The Little Rock Bartlett Pear Development Company closed a deal to develop 6,000 acres in December 1914, described by the Los Angeles newspapers as "one of the largest land development enterprises along horticultural lines to be promoted in Southern California during 1915." (Antelope Valley *Ledger Gazette*: January 15, 1915, p. 1.) Simultaneous with the new waves of speculation, established residents, landowners and previous investors found themselves on the delinquent tax lists, with their land up at public auction. The Littlerock Creek Irrigation District attempted the sale of major sections of land belonging to the Little Rock Fruitland Company, itself a subsidiary of the Palmdale Land Company. (Antelope Valley *Ledger Gazette*: January 29, 1915, p. 5.) By the late 1920s, the Little Rock Fruitland Company still held one-third of the 3,000 acres under Littlerock Creek District irrigation, and were still delinquent in their payment of water assessments. (Littlerock Creek Irrigation District: September 1928.) The Palmdale Land Company, owned by Los Angeles and Pasadena capitalists, began marketing 3,000 new acres planted in pears. Their syndicate included George P. Threasher, James Shultz, Donald Baker, C.B. Hollingsworth and H.W. Underhill. Developers anticipated that the proposed construction of the Arroyo Seco Highway from Pasadena to the Antelope Valley would boost their enterprise. (Antelope Valley *Ledger Gazette*: March 19, 1915, p. 1.) The Palmdale Land Company's chief project engineer changed again, with a return to J.B. Lippincott, the engineer who had worked with Burt Cole on the South Antelope Valley Irrigation Company's 1896 waterworks system for the same lands. (Palmdale Water Company: July 2, 1915.)

The Allin Brothers shipped their engineering files for the proposed dams to Lippincott's office in Los Angeles, including photographic surveys and drawings. Most of the "borrowed" items eventually resided permanently in Lippincott's papers at the University of California at Berkeley. (Allin: July 2, 1915; Lippincott Collection 48-2.) By late November 1915 Lippincott reported to the Palmdale Land Company that they were best advised to improve the diversion canal system and enhance the storage capacity of the Palmdale Reservoir at Harold to 10,000 acre-feet, without taking on the erection of a dam and reservoir on Little Rock Creek. Lippincott's costs for just these improvements were $441,289, more than doubling engineer Schuyler's suggested costs for essentially the same work in 1910, and approximately 12 times the actual costs allowed the Allin Brothers in 1912 for their improvements to the waterworks system. (Lippincott: 1915, cover letter.) Lippincott did discuss a future dam on Little Rock Creek, noting the best location as just above the original South Antelope Valley Irrigation Company's headworks, the site proposed by engineer Cole in Schuyler's 1910 report for the 60-foot high regulating dam. Burt Cole's survey for the proposed dam of 1910 had followed land

speculators' evolving schemes from 1910 to 1915, passing into the hands of T.D. Allin in 1912 and finally into those of J.B.Lippincott in 1915. And as Lippincott and Cole had worked together on the design of the South Antelope Valley system of 1896, the engineering team had come full circle. (Allin: July 2, 1915; Lippincott: 1915, p.7.) Of note, Lippincott described two dams, one corresponding to the 1910 "high dam" [upper dam] and one to the 1910 "regulating dam" at the South Antelope Valley/Palmdale Land Company headworks. The high dam again is noted to be 110 feet high, 650 feet across its crest and having a storage capacity of 1400 acre-feet. Again due to its difficult site, the dam is dismissed as impractical. However, a 110-foot dam is suggested for the headworks site, of 630-foot crest dimension, with a storage capacity of 3100 acre-feet. Lippincott's proposed 1915 dam for the headworks location is described as of "multiple arch concrete" type, "similar to the one which has been constructed for the Bear Valley Reservoir." Lippincott gives no credit for the dam's design, but does not claim it himself. The pivotal drawing itself does not appear to be extant. Lippincott estimated cost to be $375,000 for the multiple arch concrete dam. (Schuyler: 1910, p. 21; Little Rock Power & Water Company: 1912, p. 5; Allin: July 2, 1915; Lippincott: 1915, p.7-8.)

The 1915 reference to a multiple arch concrete dam for Little Rock Creek substantially predates the understood 1918 involvement of engineer John S. Eastwood, and, as such, is puzzling. Eastwood had invented the dam type in late 1906 during his earlier, and subsequently aborted, work with the Huntington interests at Big Creek east of Fresno. His first on-site construction for a multiple arch dam was that for the Hume Lake Dam of 1908, also east of Fresno in the Kings River watershed. Eastwood, then in business as a consulting engineer in Fresno, published his first article on his "Eastwood Multiple Arch Type" for the *Journal of Electricity, Power and Gas* in October 1909. The late 1909 article was the first public description of the multiple arch concrete dam, and the first time other engineers, like James Dix Schuyler, J.B. Lippincott, and Burt Cole, could evaluate Eastwood's ideas. Eastwood sent copies of his article to selected engineers in his professional community, but it is not known if Schuyler and Lippincott were among them in 1909. At the close of the year prominent consulting engineer Carl Ewald Grunsky wrote a second article on Eastwood's multiple arch dam, praising it highly. Grunsky had worked as both a State of California and Federal hydro-engineer from 1878 to 1907, and was well known for his writings on Central California irrigation. He, like Eastwood, had a strong artistic side complementing his engineering acumen. (Grunsky: December 25, 1909, pp.582-83; Marx: 1934, pp. 1591-95.) Eastwood published a second article on the Hume Lake Dam in January 1910 and by early 1911, Schuyler had been formally asked to comment on the Eastwood multiple arch dam. The Hume Lake Dam attained a height of 61 feet, with a crest dimension of 667 feet. In the 1910 article Eastwood included a drawing for a taller proposed dam. (Jackson: 1986, pp.273-315.) Eastwood's second multiple arch concrete dam was the Big Bear Valley Dam of 1910 in the San Bernardino Mountains about 30 miles east of Redlands. The Big Bear Valley Dam measured 92 feet high with a crest dimension of 363 feet. (Jackson: 1986, pp. 315-28.) Eastwood's third dam, planned in 1910-11, but aborted by 1913, was that of Big Meadows in Northern California for Great Western Power. Great Western

Power was directly affiliated with the Southern California Power Company and the Edison Electric Company of Los Angeles (precursors to Southern California Edison) and is the most intriguing of the trilogy.

Designed to be 110 feet high and 720 feet in crest dimension, the Big Meadows Dam made the cover of *Journal of Electricity, Power and Gas* in September 1911 and featured photographs of the Big Bear Valley Dam as illustrations of what was yet to come. Lippincott's 1915 reference to a multiple arch concrete dam of 110-foot height for Little Rock Creek, and his direct allusion to the Big Bear Valley Dam of 1910, suggests that either Eastwood had designed a dam for Little Rock Creek as early as ca.1911-12 or that there were already plans to have him carry out such a design. The Little Rock Power & Water Company, incorporated in March 1912, further raises the possibility of power company interconnections. The Owens Valley/Los Angeles Aqueduct Board of Consulting Engineers included both James Dix Schuyler and J.B. Lippincott during this same period, with Lippincott having served on a parallel Los Angeles board in 1897-98, and key to the board at its formation in 1905. In addition, consulting engineer F.C. Finkle, hired by the Littlerock Creek Irrigation District in September 1912 simultaneously with the corporate efforts of the Little Rock Power & Water Company, corresponded with Eastwood at least by 1913. Both Schuyler and Finkle had designed earlier planned, but unbuilt, dams for the Big Bear Valley project, Schuyler a rockfill dam and Finkle a concrete gravity dam. T.D. Allin and J.B. Lippincott had both worked as assistant engineers for the Bear Valley Irrigation District in 1890 and 1893, with Lippincott designing its irrigation works just prior to taking stream-flow measurements for the Hydrographic Branch of the U.S. Geological Survey for the South Antelope Valley Irrigation Company with Burt Cole in 1896. (Jones: 1942, pp. 1459-61; Volk and Rower: 1942, pp. 1543-50.)

The Little Rock Power & Water Company is a very likely point of entry for Eastwood into the evolving plans for a dam on Little Rock Creek, and the 110-foot height and 630-to-650-foot crest dimension noted by 1912 are uncannily parallel with Eastwood's multiple arch concrete dam designs of 1910-12. Eastwood had been enthusiastically supportive of hydroelectric development since the middle 1890s, and had been intimately involved with the San Joaquin Electric Company's precedent-setting work of 1895-96 as well as with Henry E. Huntington's Pacific Light and Power Company's Big Creek project of 1902-13. (Jackson: 1986, pp. 187-88; 215-47, 315-17, 400, 404-05.) Although Eastwood never patented the multiple arch dam, considering it impractical after a invention dispute with George Ladshaw in 1911-12, he was the primary engineer associated with the construction technique in the 1907-12 years and during 1913 to 1915 he wrote several articles for professional journals to promote the multiple arch dam. In March 1915 he also published the *Eastwood Bulletin*, a four page insert for *Western Engineering*, that showcased his four multiple arch dams built to date. Of these dams constructed between 1910 and 1914, three were low dams of less than 61 feet. Only the Big Bear Valley Dam approached 100 feet; it was also the only multiple arch concrete dam built for Southern California. Eastwood further showcased the Big Bear Valley Dam as the lead

illustration for his bulletin. (Jackson: 1986, pp. 426-29, 438-42.) Lippincott's November 1915 report to the Palmdale Water Company specifically referred to a multiple arch concrete dam and to the recently completed Bear Valley Dam, noting that a similar structure "has been designed" for Little Rock Creek. Although another engineer could have designed a multiple arch dam for Little Rock Creek, all indicators point to Eastwood as involved, or particularly planned for, by 1915.

In 1916-17 the Palmdale Water Company, a subsidiary of the Palmdale Land Company and successor owner for the irrigation right-of-ways developed by the South Antelope Valley Irrigation Company and the Palmdale Irrigation Company, applied to the U.S. Forest Service for an irrigation ditch right-of-way through the Forest Service's public lands under the law of March 1891. As had been true for both earlier companies a survey and field notes were required to be submitted to the General Land Office as proof of ditch and waterworks construction. The 1916 filing constituted legal completion of the 1912-13 physical reconstruction and renovation of the South Antelope Valley system by the Palmdale Water Company, and their new right-of-way was in fact identical to that of the South Antelope Valley of 1896. The earliest area ditch right-of-way, that of the Palmdale Irrigation Company, remained fully abandoned. The Palmdale Irrigation Company's ditch system had always been completely distinct from that of South Antelope Valley, as well as South Antelope Valley's successor the Palmdale Water Company. (U.S. Forest Service, U.S. Geological Service, U.S. Reclamation Service: 1916 and 1917; Palmdale Water Company: August and September 1916.)

Three events of 1917 continued to delay and change the development of irrigated land tracts and potential hydroelectric power in the Little Rock Creek watershed: the U.S. entered World War I, and the California legislature passed the California Irrigation District Act and enacted a dam safety law. (Adams: 1929, p. 17.) The wartime investment market included not only liberty loans, but also irrigation bonds. An Irrigation District Bond Commission in Sacramento reviewed the proposed bond funding for new districts as a result of the 1917 irrigation act. The difficulties of funding new irrigation districts further led directly to a linkage between hydro-electric development and irrigation: by 1929, six California irrigation districts also generated hydro-electric power for supplementary income. Irrigation specialist Frank Adams noted for the California Department of Public Works in 1929: "During the past twenty or twenty-five years [1904-09]...and especially during the past ten to fifteen years [1914-19], construction costs have increased so much, and so many new enterprises have been started, that the development and settlement of lands not previously irrigated, but for which water has been made available, have become the outstanding problem in land reclamation. The situation has, of course, been made more troublesome in recent years by the inflation and deflation period associated with the war." The accelerated development of watersheds, for irrigation and for power, and, most particularly, the failure of the Lower Otay Dam near San Diego in January 1916, in turn pushed the California legislature to create a dam safety law. The law mandated that all large dams built by organizations such as irrigation districts receive pre-construction approval by the California

State Engineer. At the close of 1917, agricultural wartime profits and their further encouragement through the irrigation district act still offset the troubled times immediate to actual U.S. entry into the fighting and the layers of complicating bureaucracy beginning to dominate Sacramento. In late November 1917 the Antelope Valley *Ledger Gazette* announced plans for a large dam on Little Rock Creek. (Adams: 1929, p. 36; McClure: 1925, pp. 13-23); Jackson: 1981, p.22-23.)

On April 15, 1918, John S. Eastwood entered into a Memorandum of Agreement with the Palmdale Water Company and the Littlerock Creek Irrigation District to design and supervise construction for a dam on Little Rock Creek. Eastwood's dam was to be one of multiple arch concrete type, 182 feet high, with a crest dimension of 634 feet, costing up to $300,000 and impounding 7460 acre-feet of water. (Scott: 1918, p. 8.) Eastwood was to deliver completed plans, detailed drawings and specifications to the Palmdale-Littlerock parties by April 20, only five days from the signing of the MOA. For his designs the Palmdale Water Company and the Littlerock Creek Irrigation District were each to pay Eastwood $500, or a total sum of $1000. Eastwood's full compensation for his supervisory role during the dam's construction was to be five percent of the dam's total cost, or up to $15,000. (Palmdale Water Company and Littlerock Creek Irrigation District: April 15, 1918.) Nearly simultaneously with the drafting and signing of the MOA, and before the due date of April 20, the Palmdale Water Company executed a separate legal document with Eastwood, noting that the Palmdale Water Company would soon be superceded by the Palmdale Irrigation District. (Palmdale Water Company: April 19, 1918.) The physical topography of the Little Rock Creek canyon; rapidly escalating costs for dam building; the recently introduced California State bureaucratic reviews and approvals imposed by the dam safety law and by the irrigation district bonds oversight; and the little-understood engineering innovations characterizing Eastwood's multiple arch concrete dam, all became immediately significant.

Choice of dam site had been an issue since the joint water rights agreement between the Palmdale and Littlerock interests in 1898. From the tum of the century forward surveyors and investors assumed that a large storage dam would be built either at the headworks of the South Antelope Valley (later, Palmdale Water Company) or at a point about five miles above these headworks just below the juncture of Little Rock Creek and its South Fork. Respectively referred to as the lower and upper sites, and as Dam Site #1 and Dam Site #2, the locations posed different construction problems and offered different storage capacities. Over their decades-long consideration the sites sponsored increasingly higher dams with greater acre-feet capacity. The upper dam, however, was always interpreted as more costly to construct than the lower dam, and for many years was understood to offer considerably less storage and to demand greater height. Schuyler recommended in 1910 that the lower dam be built first, with the upper dam under continued study and built in the future. Schuyler implies in his report that engineer Burt Cole, associated with both Palmdale and Littlerock irrigation interests since about 1890, had surveyed both sites prior to 1910. Cole's survey drawings passed to the Allin Brothers in

1911 and to Lippincott in 1915. In 1912, the Little Rock Power & Water Company adopted the upper site; only the upper site was ever considered for power development. By 1915 Lippincott talked of both sites as planned for 110-foot dams with 630-to-650-foot crest dimensions, with at least the lower dam already planned, and possibly designed, to be of multiple arch concrete type. In 1915, Lippincott and the Little Rock Power & Water Company each interpreted the upper dam as offering about 1400 acre-feet capacity, less than half that assumed at the lower site (3100 acre-feet). (Schuyler: 1910, p. 20-21; Allin: March 1912; Little Rock Power & Water Company: 1912, p. 5; Lippincott: 1915, pp. 6-8.) In 1918 yet another consulting engineer, J.W. Scott, surveyed the Little Rock Creek canyon for probable dam sites, noting four to five existed with 500 to 10,000 acre-feet capacity. Scott's selected site was that of the historically planned upper dam, with coordination for the location between Scott, Cole and Eastwood sometime prior to the August submittal of Scott's report to the Littlerock Irrigation District. (Scott: 1918, pp.6-8.) Scott also recommended the construction of a very low diversion dam at the Palmdale Water Company's headworks, the traditional Dam #1 site. (Scott: 1918, pp. 9-10.) The Palmdale Water Company filed for three official dam sites with the General Land Office in 1918, with the first and third sites coincident with their long-discussed predecessors and with an intermediate site between these two locations. (Palmdale Water Company: undated; post-June 10, 1919.)

Costs, State review and approval, and engineering technology caused the choice of the upper dam site to be changed to that of the lower site by June 1919. (Petchner: June 14, 1919; Eastwood: October 1919 and March 31, 1920.) Eastwood's first obstacle was the State Engineer William F. McClure, who, after approving the 182-foot multiple arch dam for the upper site in September 1918, retracted his approval in late November 1918 and further restricted any multiple arch dam to a height of no more than 150 feet. (Eastwood: November 27, 1918; McClure: November 25, 1918.) In an attempt to circumvent McClure, the Palmdale-Littlerock irrigation interests decided to reintroduce the dam under the auspices of the Palmdale Water Company, rather than as first tried under the Palmdale and Littlerock Irrigation Districts. As a public service corporation-backed enterprise, versus a joint irrigation district-backed enterprise, the dam fell under the umbrella of responsibilities for public utilties handled by the California Railroad Commission. Eastwood, in an attempt to save his Palmdale-Littlerock clients another 17% on the climbing costs of construction, simultaneously changed his design for the dam. His second design of December 1918 was more radical than his first, being not only of little-understood multiple arch type, but also of radial profile. Eastwood assumed that the Railroad Commission would be less conservative than had been the State Engineer, and that he could showcase both the cost-effectiveness of his dam type and its "architectural beauty." (Eastwood: December 7, 1918 and April 5, 1919.) The downstream curvature of Eastwood's radial design for the dam made some members of the engineering community extremely uncomfortable, most especially State Engineer McClure. Switching from irrigation district auspices to Palmdale Water Company auspices ultimately did not remove McClure, with both the State Engineer's Office and the Railroad Commission involved for a considerable period. In addition, the

Irrigation District Bond Commission had to approve the bond funding needed to raise construction monies for the Railroad Commission and/or State Engineer-approved dam design. (Petcher: December 18, 1918; Palmdale Land Company: May 18, 1920.)

Acceptance of Eastwood's engineering design continued to be controversial into 1919. By mid-year a third design was underway, with a change to the lower site just above the Palmdale Water Company (previously, South Antelope Valley) headworks. Construction cost savings and a lower dam height were operative: the first would help with Irrigation District Bond Commission approval, the second with Railroad Commission/State Engineer approval. At this time, Eastwood suggested planning for two dams, returning to Schuyler's 1910 position of building the lower dam first and the upper dam in the future. The lesser height of the dam removed any cost advantage for a radial design, and Eastwood suggested that both dams should be designed alike, with straight crests. Intended heights were 130 feet for each dam, with about 4000 acre-feet of storage at each as well. Irrigation District bonds were under direct discussion. (Eastwood: July 10, 1919; August 16, 1919, August 20, 1919, September 30, 1919, and October 18, 1919.) In September the Railroad Commission inspected the lower site, approving it theoretically for a multiple arch dam. Eastwood completed his third set of known plans for a dam on Little Rock Creek in early October. Once again, however, the innovative engineer had changed his basic design, and again in such a manner as to create heated professional controversy. The 1919 design for the Little Rock Creek Dam incorporated a bent of 165 degrees, open upstream. In 1924 a *Southwest Builder and Contractor* article noted: "This deviation was made to avoid carrying the foundations of the structure down into a deep chasm on the up-stream side which would have been intersected by the dam if built on a straight line." (Jackson: 1981, p. 28; "Highest Multiple Arch Dam": August 22, 1924, p. 1.) By late 1919 all references to a dam at the historic upper site were dormant.

Final approval of Eastwood's multiple arch dam for Little Rock Creek continued to vascillate between the Railroad Commission and the Office of the State Engineer, with ever-new complications imposed. Before the close of 1919 the Railroad Commission approved the third design, but required additional approval by State Engineer McClure. By early 1920 the Littlerock and Palmdale Irrigation Districts formally involved themselves again, changing the solo 1919 sponsorship of the Palmdale Water Company to a joint status and thus again placing primary approval powers in the hands of the Office of the State Engineer. McClure sought out the written professional opinions of other consulting engineers on Eastwood's design for the dam. In particular engineers Walter LeRoy Huber and Henry Hayes Wadsworth opposed the design. (Jackson: 1981, pp. 30-32.) In addition, Palmdale and Littlerock farmers began to actively oppose construction of any dam on Little Rock Creek, claiming that a dam would interfere with water already being removed from the watershed by wells. (Citizen petitions: 1919-22.) Counterpointing the established farmers' petitions opposing a dam, land speculators picked up the pace of pamphlet publication where they had left off in 1914. *Among the Pear Groves of North Los Angeles County* and *Antelope Valley* of 1920 and the *Annual Pear Day*

Festival of 1921 each promoted the Palmdale-Littlerock area. The 1920 publications featured brief discussions of Eastwood's multiple arch dam, noting approval for $582,000 in bonded expenditures. By 1920 the dam cost was assumed to be $346,000, with another $236,000 needed to improve the ditch distribution systems of Palmdale and Littlerock. Bartlett pears continued to be the crop of choice. (*Pear Groves*: 1920; Antelope Valley Chamber of Commerce: 1920; *Pear Day*: 1921.)

During 1920 at least two inter-related issues shaped the continuing controversial status of design and construction for a dam on Little Rock Creek. Post World War I, costs for hydro-engineering projects had placed traditional dam building outside the abilities of most small irrigation districts. The multiple arch reinforced concrete dam used one-fifth to one-half as much concrete as did then-standard dams, and thus was a very cost effective solution for irrigation districts during this period. The multiple arch dam required a solid bedrock interface with the dam, to preclude undercutting and failure during floods. For the Palmdale-Littlerock irrigation interests the multiple arch dam met their financial constraints, as well as being fully appropriate for the topography of the Little Rock Creek canyon. State Engineer recognized that the cost savings created by the multiple arch type were critical at Little Rock Creek, and that in 1920 only a multiple arch dam would allow those savings. McClure, however, did not feel comfortable with the multiple arch dam's greatly reduced reinforced concrete massing; in short, McClure did not understand the multiple arch dam, *as Eastwood designed it*, to be a safe dam. Undoubtedly, McClure was also uneasy over the immediate proximity of the planned Little Rock Creek Dam to the massive San Andreas fault, a seismic line of such activity as to have nearly destroyed the city of San Francisco in 1906. In August 1920 McClure asked another consulting engineer, Lars R. Jorgensen, to prepare a cost-conscious design for a constant angle single arch dam for Little Rock Creek. Jorgensen's estimate topped $800,000 and was not financially feasible. The California Debris Commission had used the "Jorgensen type of constant angle, single arched dam," also a structural type, as its standard, and, in his governor-appointed position of State Engineer from 1912 forward, McClure had significant interaction with the Debris Commission and the State Reclamation Board in its reclamation of overflow lands in the Sacramento and San Joaquin Valleys. Interestingly, Jorgensen was one of Eastwood's competitors for multiple arch dam business as well, but Jorgensen never really favored daring reductions in dam massing and hence his designs were more conservative, as well as his costs generally higher, than Eastwood's. (Jackson: 1986, pp. 625, 709, 717, 727; Eastwood: September 9, 1915; Adams and Bailey: 1926, pp. 1106-09.) In December 1920 the Palmdale and Littlerock irrigation districts themselves called in more consulting engineering expertise, through Charles Derleth, the Dean of Engineering at the University of California at Berkeley. (Jackson: 1986, p. 626.) And while costs and safety dominated the visible arguments for and against a multiple arch dam on Little Rock Creek, behind the scenes much murkier issues of land and water speculation doubtless existed.

As noted by engineering historian Donald Jackson, a hiatus in design-and-approval activity for the dam characterizes the 14 months between February 1921 and March 1922. During this period the Little Rock Power & Water Company re-enters the long-sustained competition for a dam on Little Rock Creek. In a Memorandum of Agreement signed December 1, 1921, the Little Rock Creek Irrigation District, Palmdale Irrigation District and Little Rock Power & Water Company agreed that the irrigation districts would suspend all plans for a 160-foot dam at the Palmdale Water Company headworks (Dam Site #1) and that the power company would prepare plans for two dams upstream. A steel pipe line was to connect the Little Rock Power & Water Company's dams, with a continuing pipe line to the Palmdale Water Company's headworks. At the lower of its two dams, and again at the headworks, the power company was to build power-houses to generate electricity. The Little Rock Power & Water Company's upper dam was to impound at least 5500 acre-feet of water; its lower dam, at least 2000 acre-feet. (Little Rock Power & Water Company: 1921, pp. 1-2.) The Little Rock Power & Water Company agreed to have both dams designed within 60 days, with road construction into the upper canyon under way within 15 days. Construction of the lower dam was to be started immediate to road access, with the upper dam under construction within 90 days following. The power company promised to deliver the lower dam within one year, the upper within two years. Financial arrangements benefited all parties. The Palmdale Irrigation Districts irrigation bonds of $300,000 were signed over to the Little Rock Power & Water Company, who, in exchange, granted a full half interest in the dams, pipelines and roads to the Palmdale and Littlerock Irrigation Districts. The irrigation interests received exclusive rights for water storage and irrigation distribution; the power company exclusive rights to generate electricity. The irrigation and power-generating usage of the dams by the memorandum signators had no overlap. Other contractual details addressed dam maintenance, ancillary recreational development, and potential future modifications, with a second Memorandum of Agreement between the two irrigation districts and an Operative Agreement among all three parties to guarantee no conflicts between irrigation usage and power generation. (Little Rock Power & Water Company: 1921; Littlerock and Palmdale Irrigation Districts: 1921; Littlerock Creek Irrigation District: 1921.)

With the shift to dam design and construction by a power company, the Little Rock Creek Dam came under new government reviewers. While the Irrigation District Bond Certification Commission of California still needed to approve of the financing for the dams, the California Office of the State Engineer and the California Railroad Commission, and hence William H. McClure, were removed from the process. The Federal Power Commission replaced these two agencies. The Little Rock Power & Water Company of 1921 retained its same officers as it had at incorporation in 1912, with irrigation engineer S.P. Jewett still in place as President. (Little Rock Power & Water Company: 1921, pp. 11-12.) Between 1912 and 1921, the power company's scheme had only been updated parallel with the changes in the industry. The Little Rock Power & Water Company abandoned plans for the smaller power house in the Sycamore Swamp, downstream about two miles from the 1921-planned lower dam at the Palmdale Irrigation District's (Palmdale Water Company's/South Antelope Valley's) headgates, and did

not continue its plans for a short-distance transmission line to the still-operative gold and tungsten Randsburg mines.

By March 1922, immediately subsequent to the 60-day stipulation in the Little Rock Power & Water Company's Memorandum of Agreement with the Palmdale and Littlerock Irrigation Districts, J.B. Lippincott also re-entered the scene. Evidently the power company could not carry out its part of the agreement, and once again the Palmdale-Littlerock dam-building interests were faced with ever-more complicated California reviews and approvals as well as with escalating costs. Lippincott, like Burt Cole, had been involved in various plans for the Little Rock Creek watershed since the 1890s. Hired by Sheldon & Lancaster, investment brokers of Los Angeles, Lippincott reported in April 1922 that a dam at the lower site should not exceed 145 feet in height, in accordance with the opinions of State Engineer McClure. Lippincott noted that the irrigation bonds were secure and that the return on investments promised to be spectacular. Although no new pears had been planted since 1915 due to lack of water, fruit growers were still planning on the construction of a pre-cooling shipping plant at Palmdale in the summer of 1922 to accommodate their successful industry. Lippincott closed his report by noting that the Memorandum of Agreement with the Little Rock Power & Water Company was still pending, and that the irrigation districts could still forfeit their dam building to the power company, exchanging $300,000 in irrigation bonds for 7500 acre-feet of water storage at two new dam sites. Lippincott's accompanying map of the Little Rock Creek watershed summarized events to date, illustrating the proposed irrigated acreage, the two diversion canal systems to Palmdale and Littlerock, the Sycamore Swamp-Garcia Cienega headworks, the long-planned for Palmdale Irrigation District (Palmdale Water Company/South Antelope Valley) headworks dam, and the two power company dams further up the canyon. (Lippincott: 1922.) In October 1922 the Federal Power Commission issued a license for the Little Rock Power & Water Company's project. Yet no construction followed. In May 1924 the California Department of Public Works cancelled applications and permits filed by the Little Rock Power & Water Company; in February 1925 the Federal Power Commission terminated the power project's license for failure to begin construction. The Little Rock Power & Water Company, however, was still extant on paper in late 1929, still attempting to file for construction of power-generating dams on Little Rock Creek. (California Department of Public Works: May 29, 1924; U.S. Geological Survey: October 8, 1927; Federal Power Commission: January 25, 1928; Petchner: October 24, 1929.)

In May 1922 the Palmdale and Littlerock Irrigation Districts signed yet another joint agreement, then describing the Little Rock Creek Dam as 145 feet high and of $400,000 projected cost. The dam was to be constructed according to Eastwood's plans and specifications, "as amended by Mr. J.B. Lippincott." (Littlerock Creek and Palmdale Irrigation Districts: May 2, 1922, pp. 1 and 4.) In the same month State Engineer McClure finally approved Eastwood's design for the Little Rock Creek Dam, following specific reinforcement modifications to be implemented by Lippincott and Cole. McClure first agreed to a dam height of 158 feet, but then again stipulated that the dam height was not to exceed 145 feet. Of note, McClure approved a

straight-edged dam, as had been explicitly described by Lippincott in his April 1922 report: "The dam is laid on a straight line." (McClure: May 16 and May 18, 1922; Lippincott: April 1922, p. 19.) Eastwood's design of October 1919, still the design under consideration, was for a dam with an angle, opening upstream. Thus, in May 1922 all parties thought that Eastwood's angled dam would be modified to conform with a straight-edged design. By June 1922 the Bent Brothers, who had reconstructed and renovated the ditch system for the Palmdale Water Company in 1911-12, were under contract to build the dam and further update the ditch system. The Bent Brothers had a history of building Eastwood's concrete multiple arch dams, with two recently completed in San Diego County, the San Dieguito and Lake Hodges Dams, both of 1918. (Eastwood: March 15, 1919, pp. 265-66.) In the construction contract the State Engineer retained the right to examine and inspect the work in progress. In July, before initiation of the contract, Professor Derleth prepared a formal report on the Lake Hodges Dam in San Diego County, an Eastwood multiple arch dam and a close model for that designed for Little Rock Creek. Derleth did not recommend against the multiple arch dam type and construction began at Little Rock Creek in August 1922. (Derleth: November 26, 1923; Jackson: 1986, pp. 628-29; "Highest Multiple Arch Dam": August 22, 1924, p. 46; Littlerock Creek Irrigation District: August 1 and 26, 1922.)

The Bent Brothers began construction for Eastwood's angled dam of 1919, with McClure and Lippincott assuming that a straight-edged dam was in progress. They apparently remained unaware of the situation until May 1923, even though a representative from the State Office of the Engineer visited the dam about once a month between late 1922 and early 1924, and not withstanding the fact that McClure signed off on a Burt Cole-approved drawing of the angled dam in November 1922. In Lippincott's correspondence the State's diligence at on-site inspections is characterized dubiously. (Jackson: 1981, p. 40; Eastwood and Cole, with McClure approval: September and November 1922; Lippincott: June 25, 1923.) Monitored in-progress construction further rendered it obvious that the height limitation of 145 feet would be exceeded by 25 to 30 feet. Thus in late June 1923 Lippincott formally complained to the Palmddale-Littlerock interests and to the Bent Brothers that in his judgment "the design as it stands is inadequate and may lead to serious consequences. ... While the dam can be completed successfully with the horizontal angle in it, it would require, in our judgment, certain substantial modifications..." Lippincott copied McClure with his opinions. At this point, Lippincott also noted that he was once more bringing in Derleth for a second opinion. (Lippincott:June 11, 1923, pp. 1-2.) By mid-July 1923, both Lippincott and McClure had satisfied themselves as to the safety of the angle in the dam, again with the support of Professor Derleth. Lippincott wore many professional hats, at times finding himself in near conflict of interest positions. He appears to have raised his concerns about the angled face of the Little Rock Creek Dam in order to get Derleth to Southern California to conduct an on-site inspection of Eastwood's Lake Hodges Dam. Lippincott had been asked for his paid opinion on the Escondido dam as a stipulation of eminent sale; simultaneously he consulted as the engineer for the irrigation bond house and the Bent Brothers contractors for Little Rock Creek. (Lippincott: July 13, 1923.)

Derleth may well have been aware of, or involved in, the speculation over water development, but by late August 1923 he was also compiling a thorough bibliography on multiple arch dams. Derleth's file focused on the reinforced concrete dams of Eastwood and Jorgensen, and on hydroelectric dams in Italy. In December 1923 the multiple arch dam at Gleno, in northern Italy, failed, adding to the controversy continuing over the safety of the dam type. The Gleno Dam failed due to its masonry gravity substructure, not due to problems derived from the reinforced concrete multiple arch component; yet the imagery of failure remained. (Lippincott: June 11 and 25, 1923; Derleth: August 14, 1923; Jackson: 1986, pp. 695-98.)

State Engineer McClure officially accepted the Little Rock Creek Dam as complete on June 5, 1924. (McClure: June 5, 1924.) The dam was the highest reinforced concrete multiple arch dam in the world when finished, second in height to a masonry-buttressed multiple arch dam at Tirso, Italy, of the same years. (Jackson: 1981, p. 47.) Irrigation bonds totaled $750,000 for the Palmdale and Littlerock districts, acknowledging that dam building costs had nearly quadrupled since consulting engineer Schuyler's $200,000 estimate of 1910. Of these costs, the Bent Brothers construction contract accounted for $600,000. While the Little Rock Creek Dam was under construction as many as 116 men occupied a workers' camp immediate to the downstream face of the dam. The Bent Brothers provided "good living accommodations...including a super-hetrodyne radio." ("Highest Multiple Arch Dam: August 22, 1924, pp. 45-46.) Cycles of intense drought and desert flash flooding continued to characterize the Little Rock Creek watershed throughout its irrigation history. Just as the 1886 to 1896 years had been wet and promising for agriculture in the area, so had unfolded the 1906 to 1916 years. And just as the 1897 to 1905 years had been very dry, so developed the 1917 to 1925 years. Thus for the first two years of its active life the Little Rock Creek Dam held no water, lacking sufficient rainfall to allow the fill of the reservoir it had created. And then, dramatically, yet predictably, on April 4, 1926, heavy desert rains filled the reservoir in three days. (Eaton: November 25, 1926, p. 29.) Thus, fully 40 years had passed between the 1886 efforts of the first irrigation company for the Palmdale-Littlerock vicinity, the Palmdale Irrigation Company, and an on-line status for a large storage dam on Little Rock Creek.

In mid-1927, the Palmdale Irrigation District filed to the U.S. Forest Service for yet another irrigation ditch right-of-way through the Forest Service's public lands under the still-governing 1891 law requiring proof of ditch and waterworks construction. Palmdale irrigation interests' 1927 filing of survey maps and field notes for a ditch alignment beginning at Little Rock Creek and running northwestwards represented the fourth iteration, following those of 1894, 1896 and 1917. The 1927 filing verified the Bent Brothers 1922-24 updating of the ditch system and the construction of the headworks dam; ditch alignment was substantially that filed in 1896 and 1917, with one significant change. In the northeast quadrant of Section 21, Township 5 North, Range 11 West, a 666-foot tunnel replaced an abandoned segment of the pre-existing ditch of 1896. (Schoeller: November 16, 1926.) Palmdale Irrigation District's chief engineer, H. Paul Schoeller, conducted the 1927 survey. (Palmdale Irrigation District: June 15, 1927; Schoeller:

June 24, 1927.) Almost immediately the Office of the State Engineer continued its critical analysis of the Little Rock Creek Dam. By December 1927, Edward Hyatt, who had succeeded in McClure's position following McClure's death in 1926, noted that a site visit had revealed serious leakage in two of the dam's bays as well as at the underfaces of many of its arches. Hyatt suggested a protective coating for the upstream face of the dam was needed. (Hyatt: December 1, 1927.)

In July 1929 the State of California adopted a more stringent dam safety statute, following the tragic loss of life caused by the failure of the St. Francis Dam in the Santa Clara Valley of Southern California in March 1928. The statute closed the loopholes left in the 1917 law, now requiring review for the design and engineering of all dams and creating the California Division of Safety of Dams. (Markwart: 1930, pp. 828-35.) The Palmdale and Littlerock Irrigation Districts, as required, filed an "Application for Approval of Dams Built Prior to August 14, 1929," in accordance with the statute. During the 1930-32 years the State inspected the Little Rock Creek Dam, increasingly uneasy regarding its cracks, its presumed behavior under flood conditions, and its proximity to the San Andreas fault. A State-sponsored Multiple Arch Advisory Committee composed of independent engineers further reviewed the Little Rock Creek Dam, deciding that it was an unsafe structure in its present condition. In August 1932 the State ordered the Palmdale-Littlerock Districts to improve the spillway capacity to prevent flood overtopping; to protect the foundations against erosion; to stop leakage through the dam face; to drain the foundation; and, to strengthen the dam for increased safety. Work was to begin by October 1932, with completion by the close of the year. (Woodward-Clyde: 1987, p. A-1; Hyatt: August 13, 1932.) In November, with no work yet underway, the California Institute of Technology at Pasadena, also commented on the Little Rock Creek Dam as "in a critical condition of instability." (Schoeller and Smits: November 18, 1932.)

Due to the Depression, the Palmdale and Littlerock Creek Irrigation Districts once again faced a severe problem of funding. The State claimed to be exceptionally careful in its demands, with knowledge that money for repairs was not to be had. By February 1933 Palmdale's engineer Schoeller did file an application to "cut an emergency spillway 30 ft. wide in rock around West end of dam, 10 ft below present crest of siphon spillway, to lower the storage capacity 10 ft." The alteration was to take pressure off the dam and in effect create a second spillway until substantive repairs could be made. Schoeller noted, "It is contemplated to use the unemployed through the County Welfare Dept. on this work." (Schoeller: February 9, 1933.) During October-November 1933 the Civilian Conservation Corps established a work camp about three-quarters of a mile north of the Little Rock Dam face. Staffed by America's unemployed, the C.C.C. camps undertook public construction projects. At the Little Rock Creek camp an administration building, a medical building, a Forest Service headquarters building, a mess house and four bunkhouses provided quarters for about 200 men. The C.C.C. built over 30 miles of fire access roads into the lands above the dam, as well as installing telephone lines. Originally the access road to the dam ran through the work camp, but as the construction concluded the

road was realigned to the west of the camp. It is likely, although not verified, that the C.C.C. camp also housed the workers repairing the dam itself. (Mendenhall: 1962; "C.C.C. Camp": October 12, October 26 and November 23, 1933; U.S.G.S. Mount Emma: 1935.) Most of this work was completed by December 1936. The Reconstruction Finance Corporation provided a loan for partial funding, and the Works Progress Administration undertook the work at a greatly underwritten cost. The irrigation districts decided not to waterproof the face of the dam, due to the expense, and continued to study the leakage. An ancillary W.P.A. project scheduled for 1937 was to have replaced the wooden trestle below the dam with a concrete structure. The concrete trestle replacement remained unbuilt. (Carr: October 26, 1936.)

Simultaneous with early 1930s safety modifications to the Little Rock Creek Dam, the Littlerock Creek Irrigation District upgraded its ditch system and storage reservoir in the Sycamore Swamp. The district placed a 16-inch steel pipeline through the underground reservoir, connecting it to a new diversion point on the Palmdale Irrigation District's ditch at the western edge of the C.C.C. camp. By the 1950s the U.S.G.S. mapped the diversion point as "Little Rock Station," with most of the C.C.C. buildings removed. The two irrigation districts signed a legal agreement for the new diversion on August 2, 1932, with the concrete diversion gate itself inscribed "November 31, 1932." (Schoeller: November 18, 1931; Palmdale and Littlerock Irrigation Districts: August 2, 1932; Weitze and Davis: May 25, 1993.)

On March 1 and 2, 1938, full alteration of the siphon spillway remained unaccomplished, and with an intense two-day storm the facility's capacity failed to keep pace. Water overtopped Little Rock Creek Dam; the structural barrels of the spillway collapsed; flooding occurred. As had been true in 1908, the sudden flooding washed out part of the concrete flume (250 feet), the wooden trestle (400 feet) and the concrete-lined ditch (830 feet) immediately below the face of the dam, thus cutting off the irrigation ditchworks for both the Palmdale and Littlerock Irrigation Districts from their source. (Schoeller: April 28, 1938.) State flood damage funds paid for a new open channel spillway,as well as for new sections of concrete flume, wooden trestle and concrete ditch. Salvaged 70-foot long wooden booms, owned by the Bent Brothers and washed three miles down the canyon, provided the lumber for the trestle construction. (Schoeller: April 26 and May 4, 1938; Littlerock Creek Irrigation District: August 8, 1938.) By May the irrigation districts had again applied for a W.P.A. project to construct the spillway, with paperwork updated in December. The project employed 33 men. (Cowell: May 4, 1938; Schoeller: May 10, 1938; W.P.A. Application No. 30072: December 3, 1938.) Repairs, including several new reinforced concrete tunnels along the ditch alignment, were officially completed in May 1939, with an extension to the outlet screen at the dam face in late 1940. (Woodward-Clyde: 1987, p.A-2; Schoeller: November 30, 1940.) The 1938-40 modifications to the dam spillway and outlet screen, and to the Palmdale Irrigation District ditch system, completed the design and construction of the Little Rock Creek Dam. Incidentally, perhaps, a private citizen, Lew Sahagan, filed for a Forest Service permit in October 1939, to build a small campground on the western edge of the reservoir behind the dam. The campground offered

recreational facilities for fishermen, boaters and hunters, a use for the reservoir understood and planned for decades earlier. Sahagan's was the third "camp" in the immediate vicinity; the 1922-24 construction workers' camp at the dam's face and the C.C.C. camp three-quarters of a mile below the dam were both of temporary duration. Sahagan's remains today. (Mendenhall: October 31, 1939.)

John S. Eastwood and the Civil Engineering Community, 1886-1940

Born near Minneapolis in 1857 to a first-generation Dutch immigrant farming family, John S. Eastwood's professional engineering career straddles two distinct eras. Like most American civil engineers who were born before the Civil War, he received a limited education, yet accomplished several years of technical, university-level education in mathematics and related subjects. Most of the American civil engineers born after the Civil War, or at least post-1863, were more likely to come from an already-established professional family and were able to complete a Bachelor's of Science in Civil Engineering. Common to both the pre- and post-1863 engineering group, Eastwood and his American colleagues typically began their careers working for Westward-expanding railroads as surveyors and construction engineers, often settling in the Far West and establishing themselves as independent businessmen. Most of the group at some time worked for a municipal, State or Federal agency; most helped to subdivide land and participated in land speculation; many were involved in the development of large-scale irrigation and hydroelectric power systems. Of the other key civil engineers involved in the multi-decade planning, design and review for a dam on Little Rock Creek, Eastwood's chief rival William Henry McClure, prominent practioners James Dix Schuyler and Edward Wegman, and pioneering concrete contractor Arthur Samuel Bent were his contemporaries in age, education and pioneering spirit. Wegman, although in no way directly touching the Little Rock Creek Dam, actively wrote and reviewed the multiple arch dam type, inclusive of Eastwood's central role in its promulgation.

Schuyler (1849-1913) arrived in Stockton in 1873, working as a railroad engineer and by 1878 appointed Chief Assistant State Engineer in charge of irrigation investigations for the Central Valley under William Hammond Hall. During 1891-95 he consulted on the Lake Hemet Dam, one of the highest masonry dams then built in Western America. His work from the 1890s forward consistently focused on large, high dams associated with power projects, with commissions from Mexico and Hawaii to Japan. (Kieffer, Grunsky and Lippincott: 1913, pp. 2243-45.) His 1910 suggestion to the Chicago Exploration Company for a 150-foot high dam on Little Rock Creek was the first known call for a high dam on the waterway. Schuyler's dams were of masonry construction, although his daring with regards to size and height directly paralleled Eastwood. (Schuyler: 1910, p. 21.) Eastwood and McClure also arrived in California very early, in the same year, 1883. William Henry McClure (1856-1926) attended the Southwestern Normal School southeast of Pittsburgh, Pennsylvania. He studied engineering

while a teacher, and in 1879 began working as a engineer for the St. Louis and San Francisco Railroad. By 1882, he surveyed land and townsites for the railroad, arriving in Los Angeles the next year. His California career veered in several directions near the turn of the century. During the 1890s he worked as a missionary in the Sierra Nevadas. After 1900 he took up construction engineering with dredging work in the San Francisco Bay. Ultimately, he became the City Engineer of Berkeley in 1905, and the State Engineer in 1912. (Adams and Bailey: 1926, pp. 1106-09.) Of note, both Schuyler and McClure worked in the State Engineer's office in Sacramento, 1878-82, and 1912-26, respectively, and both were well informed about California's largest and most enduring irrigation and power projects.

Eastwood's two other contemporaries involved on the Littlerock Creek project resembled each other through their innovative spirit as engineers and contractors. Edward Wegman (1850-1942), although an early American engineer, was well educated, holding a Civil Engineering degree from New York University. His first work with railroad construction, 1871-84, followed with the design and construction of aqueducts and dams. In 1888 he published *The Design and Construction of Dams*, a comprehensive look at the history of masonry dams up until that time. In 1900 he designed a multiple arch dam of 160 feet (unbuilt), one of the forerunners of Eastwood's own work. (Wegman: 1927, p. 470.) He revised and updated his book on dams into the late 1920s, and in his eighth edition included an entire chapter on multiple arch dams worldwide. Although his involvement with Eastwood was only through his discussions of the multiple arch dam type, it is interesting that he himself was one of the very few designers of a multiple arch dam before Eastwood's success in 1908. (Thomson: 1942, pp. 1858-62.) Arthur Samuel Bent (1863-1939), in contrast to Wegman, was very modestly educated, yet in parallel with Wegman pioneered waterworks systems by the early 1880s. Bent's father, Henry Kirke White Bent, initiated the irrigation works for the Littlerock area in the middle 1880s, with Bent himself manufacturing concrete pipe for irrigation systems beginning in 1883. In 1891 the younger Bent constructed the main water-supply system for the Temescal Water Company in Riverside County. Construction of concrete pipe and irrigation canal systems led to larger waterworks structures. His later company, the Bent Brothers, contracted for the construction of 18 dams between 1920 and 1939, all but one of reinforced concrete type. The Bent Brothers built a number of Eastwood's multiple arch dams. (Lippincott: 1939, pp. 2056-58; Eastwood: March 15, 1919, pp. 265-66.)

A third professional group of civil engineers characterized the late 19th and early 20th century working environment. Generally speaking, these engineers were younger, technically well educated, early involved in the development of hydroelectric power, and well versed in the quick-paced innovations associated with the concrete industry. Several were foreign-born, educated or experienced. In addition to Eastwood, Schuyler and McClure, the key civil engineers surrounding the design and construction of the Little Rock Creek Dam, and the subsequent professional review of the multiple arch dam type, included Burt Cole (whose family early resided in the Palmdale-Littlerock area), Carl Ewald Grunsky (1855-1934), J.B. Lippincott

(1864-1942), Lars R. Jorgensen (b. 1876), Frank Ellsworth Trask (1863-1944), Thomas David Allin (1864-1942), Henry Hayes Wadsworth (1865-1923), John Debo Galloway (1869-1944), Walter LeRoy Huber (1883-1961), Charles Derleth, H. Paul Schoeller (whose family also early resided in the Palmdale-Littlerock area), Bernhard Faaborg Jakobsen (b. 1881) and Fred Adolph Noetzli (b. 1887). A number of these men interested themselves in the design and construction technology of dams; an overlapping group focused their attentions on design and structural innovation in reinforced concrete, with special attention to seismic concerns. Most of these men, as well as Schuyler, McClure, Wegman and Bent, had heavily overlapping careers, working with and against each other on many occasions.

Eastwood took his basic training in mathematics at the University of Minnesota, following his education with a three-year stint as a surveyor for the Northern Pacific Railroad. He arrived in Fresno, in central California, in 1883. In 1885 Eastwood became the first City Engineer for the newly incorporated town. By 1886 he had started working in the Sierra Nevadas on a 54-mile flume for transporting cut lumber to the San Joaquin Valley floor. Soon he moved on to the Fresno Flume and Irrigation Company. In 1892 he acted as Chief Engineer for the Sunset Irrigation District south of Fresno, designing and overseeing the construction of its water distribution system. The irrigation district, like most under the Wright Act of 1887, failed financially, and by 1894 Eastwood had again moved on, pursuing the design and construction of hydroelectric power systems. In 1895 Eastwood became the Chief Engineer for the San Joaquin Electric Company. Eastwood's first truly significant commission, that for the San Joaquin Electric Company included seven miles of flumes and ditches, a 4020-foot long steel penstock and an 11 kilovolt, 35-mile transmission line. On line in the Spring of 1896, the San Joaquin Electric Company delivered power to irrigation pumps, to the Fresno Water Company and to Fresno's Sperry Flour Mill. The company accommodated street and residential lighting as well. The Fresno hydroelectric project was California's third, following upon those of Redlands (1893) and Folsom (1894-95). In 1895 as well San Francisco became home to an electrical power and technology journal, the *Journal of Electricity* (later the *Journal of Electricity Power and Gas*). In 1897 Eastwood presented and published a paper on the San Joaquin Electric Company's 35-mile transmission line for the *Journal*. By 1898 Eastwood had upgraded the line to 16 kilovolts and extended it another 30 miles. Success seemed eminent for Eastwood and his business partner the San Joaquin Electric Company.

The turn of the century hinted at the future for development of hydroelectric power in California. Water rights, and manipulation of these rights, came quickly to the forefront, as did the cyclical drought pattern of the region. The late 1890s were very, very dry, and a competing power company soon figured out how to divert water out of the utilized river bed above the headworks for the San Joaquin Electric Company. Both the water rights litigation and the climate pointed to the need for water storage, bringing Eastwood's attention to the design and construction of dams. In 1899 the San Joaquin Electric Company went into receivership and in 1902 Los Angeles businessmen purchased the operation. Ultimately Pacific Gas and Electric

absorbed the reorganized company. Eastwood continued to plan for hydroelectric developrnent in Central California, with the Mammoth Power Company looking for investors by 1901. Eastwood planned to harness the water power of the San Joaquin watershed through a series of power plants; the plants would draw on a cumulative water drop of more than 6000 feet. Eastwood caught the attention of entrepreneur Henry E. Huntington and the Pacific Light and Power Company of Southern California in 1902, with an agreement to survey and design what would become named the Big Creek project. The Big Creek hydroelectric systern, now under Southern California Edison, signaled Eastwood's entry into large-scale darn design. Eastwood immediately began to explore alteratives to the then-accepted traditional dam design. In 1906 he designed his first reinforced concrete multiple arch dam for the Big Creek project. Unbuilt, the dam foreshadowed the engineer's future. Between 1907 and 1910 Eastwood's relationship with the Huntington interests deteriorated, and ultimately the shrewd Southern Californians passed over his hydroelectric system and cut him out of all financial gain from the very lucrative project. In late 1913 Big Creek went on line at 150 kilovolts over a precedent-setting 220-mile long transmission line to Los Angeles. By the 1940s the Big Creek system generated more than one third of Southern California Edison's power.

The San Joaquin Electric Company and Pacific Electric and Power Company projects, fiascos though they were for Eastwood, clearly focused the engineer on the design of hydroelectric power systems, particularly on innovative design solutions for the large storage dam. Hydroelectric power sites were often difficult engineering problems, while investment funding was usually leveraged and manipulated to create more from less. Eastwood's attention sharply addressed these problems through the technology of reinforced concrete and the design of the multiple arch dam. Between 1908 and 1924 Eastwood continued to advance a refined reinforced concrete multiple arch dam through successfully completed projects for 16 California, Arizona, Utah, Idaho and British Columbia locations, as well as for one aborted project in Northern California. He designed more than 30 additional dams that remained unbuilt for hydroelectric power systems and irrigation projects throughout California, the Southwest and Mexico. Completed and partially-completed dams included the Hume Lake (1909), Bear Valley (1911), Big Meadows (aborted, 1911-13), Los Verjeles (1913-14), Kennedy (1914), Argonaut (1916), Murray (1917), Lake Hodges (1918), San Diequito (1918), Eagles Nest (1917-18), Little Rock Creek (1918-24), and Webber Creek (1919-24) California dams; the Cave Creek (1921-23) Arizona dam; Mountain Dell (1915-17) Utah dam; Malad (1917) and Fish Creek (1919) Idaho dams; and the Anyox (1921-24) British Columbia dam. Dam heights ranged from a low of 36 feet (Eagles Nest, Warners Springs, California) to a high of 175 feet (Little Rock Creek, Littlerock, California). Crest dimensions ranged from 120 feet (Eagles Nest, Warners Springs, California) to 2600 feet (Fish Creek, Carey, Idaho).

Of the 17 built and partially built reinforced concrete multiple arch dam designs, five were directly undertaken for, or clearly one-time associated with, the development of hydroelectric power plants. Three of these four dams, Hume (1909), Bear Valley (1911), Big Meadows

(1911-13) and Webber Creek (1919-24) are products of Eastwood's career at early and late dates. The fourth, the Little Rock Creek Dam (1919-24), dates to Eastwood's late career in its actual known design and construction, but was associated with plans for a hydroelectric power development and a multiple arch dam from the 1912-15 years. Interestingly, during his final career years, 1919-24, Eastwood returned intensely to designing hydroelectric power systems, with his designs for multiple power plants and dams resembling the complexity of inter-related units found in his plans for the Big Creek system of 1902-10. His late-career hydroelectric designs include that on the Sespe-Piru Creek for the Sespe Light & Power Company of 1919-26; that on the Pit River for Pacific Gas & Electric Company of 1918-19, ultimately designed and built by Frank Baum; that on the Kings River for the San Joaquin Light & Power Corporation of 1919-22, including work on the Wishon, Cliff, Coolidge Meadows and Dinkey Creek storage dams ultimately constructed; that on the Salt River at Mormon Flat for the Salt River Valley Water Users Association of 1923; and, that on the Colorado River at Diamond Creek of 1923, with the project planned since 1916. In addition to Eastwood's hydroelectric dams, nine of his dams were constructed for irrigation (with secondary land subdivision and municipal water storage secondary in some cases), three for mining enterprises, one for flood control and one solely for municipal water storage. The Bear Valley and Little Rock Creek watersheds sponsored his most influential and controversial dams, respectively, and were complex stories unto themselves. Planning for these two watersheds extended back into the middle 1880s, with both irrigation and hydroelectric power systems planned repeatedly over the decades. Among the unbuilt irrigation dams were three for Mexico during 1922-24, that for Sinaloa; that for the Bluewater-Toltec Irrigation District; and, that for the Balojaque Dam near San Blas, as well as several for San Diego County.

The Multiple Arch Dam: Controversial Innovation

The multiple arch dam, largely credited to John S. Eastwood as a technological type adapted to reinforced concrete, peaked in popularity during the 1920s, with few constructed after 1930. From 1908 to 1933, the multiple arch dam attracted proponents primarily due to its substantially lower cost. In some cases, a multiple arch dam required only 25% of the concrete needed for a gravity dam, with typical cost savings of between 20% and 40% overall. (Noetzli: 1927, p. 439.) Using much less poured concrete than traditional gravity dams, the multiple arch dam stayed competitive until the increasing costs of the needed, extensive wooden forms offset the reduced cost of the concrete. At a time when irrigation districts, water companies and hydroelectric power corporations all vied to create futuristic systems over large land masses, the multiple arch dam also offered artistic imagery. Engineers, including Arthur H. Markwart, John Debo Galloway and Walter LeRoy Huber associated with Pacific, Gas & Electric, wrote about "engineering as art" in the journals of the time. With regards to powerhouse and hydroelectric dam architecture, Markwart wrote a series of articles in 1928-29 for *Power Plant Engineering* entitled "Art in the Electric Industry," "Beautification of Power Plants and Substations," "It Pays

to Build Beautiful Plants," and "Engineers and Architects Must Cooperate to Build Beauty into the Power Plant." (Hay and Corbett: 1992, p. 26.) Galloway and Huber were both personally very interested in art and in history. Galloway taught drawing at the California School of Mechanical Arts in San Francisco just before the turn of the century; he was the junior partner to Arts and Crafts architect John Galen Howard for some years; and, he was a steadfast member of the California Historical Society. Huber, too, was a member of the California Historical Society, with an appointment to the Advisory Board of National Parks, Historic Sites and Buildings and Monuments late in his career. (Huber: 1944, pp. 1451- 56; Hall: 1961, pp. 27-28.) In France, engineer Considère commented that his multiple arch dams of the 1916-23 years were "according to the principles of reinforced concrete bridge design." Recognition, *at the time*, of such design aesthetics as those of Swiss engineer Robert Maillart (1872-1940), in his reinforced concrete bridges of eggshell thickness that eliminated all non-functional elements and culminated in his most elegant designs of the 1920s and 1930s, echoes the artistic quality associated with the multiple arch dam type of the same period. Even Eastwood's biographer, Donald Jackson, devoted entire appendix of his dissertation to "John S. Eastwood and the Structural Art of the Multiple Arch Dam," noting the elegant, expressive aesthetics present in the multiple arch type as designed by Eastwood. (Jackson: 1986, pp. 789-823.) The Eastwood multiple arch dam represented a marked departure from dams designed up until its time and can be associated with a fresh design interpretation for the medium of reinforced concrete, characterizing especially the decade of the 1920s.

If reduced cost and breath-taking aesthetics argued for repeated construction of the multiple arch dam, intense worry over its long-term safety counterbalanced its popular and professional reception. From nearly its first submittal to the Office of the State Engineer, the Little Rock Creek Dam made more than a few engineers uneasy. The dam's relatively small massing of reinforced concrete for its extreme height may well have been the root cause of McClure's persistent desire to stop the building of a multiple arch dam on Little Rock Creek. The security of a multiple arch dam's foundations, as well as the capacity and predictable functioning of its spillway, became of tantamount concern. Two of the consulting engineers who advised McClure on the design of the Little Rock Creek Dam, Galloway and Huber, also all disapproved the dam's design. Galloway was an early advocate of earthquake-proof design and construction, while Huber also was known as an authority of earthquake resistance and had many publications on seismic stresses to his credit. The Little Rock Creek Dam's site, immediately adjacent to the San Andreas fault, was of major concern. (Of ironic note, it was also Galloway and Huber who were among the most vibrant advocates of engineering as art.) Charles Derleth, Dean of the College of Engineering at the University of California at Berkeley, was yet another professional consulted by McClure whose work focused on reinforced concrete and seismic strength. Derleth's leadership of committees of engineers assessing the structural damage prominent throughout the San Francisco Bay Area resultant from the 1906 earthquake defined much of his later career. On December 1, 1923, the Gleno Dam in the Italian Alps failed within 30 days of its reservoir filling. A multiple arch dam, with an unusual and poorly designed masonry base

and upper reinforced concrete arches, the Gleno focused professional attention on the experimental type. Clearly failure was due to an insecure foundation, but with 500 people dead, destroyed property and the terror of 4300 acre-feet of water emptying its storage in less than half an hour, the blame focused itself on the multiple arch design in general. (Noetlzi: 1927, pp. 513-16.) Although dams had failed throughout history, their increased water storage capacity and their siting near to growing urban areas augmented professionals' fears throughout the developmental years of the multiple arch dam, particularly as their very cost-effectiveness caused them to be undertaken in greater numbers following World War I.

Less than five years after the Gleno failure, in March 1928, the St. Francis Dam in Southern California's Santa Clara River Valley also failed catastrophically. Engineers, public officials and the populace all looked harder at issues of dam safety. The actual reason(s) for the failure of St. Francis are still arguable, from landslides on its eastern abutment to water-saturated rock on its western abutment to dynamite placed in the violent struggles between the populace and the Los Angeles Department of Water and Power. Failure, however, was perceived to have occurred due to undermined, washed-out foundations and increasing leakage in the face of the dam, both constant fears for the multiple arch dam type. More than 400 people died in the catastrophe, with over 1200 buildings destroyed. These figures are magnified when consideration is given to the rural character of the St. Francis-affected landscape, and to the dam's traditional design as a gravity structure. An unbelievable 38,000 acre-feet of water emptied from St. Francis in about 70 minutes, with fully half that quantity emptying in less than 15 minutes. (Outland: 1977, pp. 66, 185, 217, 221-37, 254.) In 1929, *Transactions of the American Society of Civil Engineers* noted that of the 293 partial or complete dam failures tabulated worldwide since 1799, California's failed structures ranked second after Pennsylvania with 26 failures. Of note, 159 of these dams were earthen and 67 gravity masonry, only seven were either single or multiple arch, reinforced concrete constructions: thus Eastwood's multiple arch type really maintained an excellent safety record, fears to the contrary. (Hinderlider: 1929, p. 837.) Many professional engineers remained skeptical of the multiple arch dam's experimental qualities, throughout its history and to this day. Immediately following the St. Francis failure, McClure's successor as State Engineer, Edward Hyatt, appointed Huber to head a task force in studying the safety of multiple arch dams; Huber stood fast against the technology, even largely ignoring the inclusion of the type in a history of dams that he wrote in the 1950s. In 1933, a major earthquake in Long Beach only heightened fears for the Little Rock Creek Dam near the San Andreas Fault, and for multiple arch dams in general. (Jackson: 1986, pp. 754, 759, 762.)

Although the multiple arch dam type began to be discussed as early as the 16th century in Spain, the first known major multiple arch dam dates to about 1806, when a French engineer named Russle designed and built a 39-foot high masonry multiple arch dam, the Meer Alum, in India. (Jackson: 1986, p. 119.) Nearly a century passed before the multiple arch dam design type was undertaken again. In 1892 a British engineer, J.D. Dickson, took out a United States patent on

the type, but built no dams. In 1897 Henry Goldmark designed a multiple arch dam of 105 feet for an irrigation project in Utah; the dam went unbuilt. The next year, in 1898, a multiple arch dam, the Belubula Dam, did see construction, with concrete base and brick upper section, in Australia. In 1900, Edward Wegman designed a multiple arch reinforced concrete dam of 160-foot height for a project in Virginia, near Washington, D.C., also unrealized. Engineering and architectural experimentation in reinforced concrete paralleled the turn-of-the-century fascination with the multiple arch dam, with sporadic attempts at the design type continuing. In 1901, engineer George L. Dillman published an article on the type's cost savings in *Transactions*; in 1902, engineer Gardiner S. Williams designed the Six-Mile Creek Dam near Ithaca, New York, (contract let, but unbuilt); and in 1903, engineer Edwin Duryea of San Francisco designed two multiple arch dams for California projects (unbuilt), with heights of 138 and 30 feet. Between 1897 and 1902, at least two other engineers, James H. Fuertes and Emil Kuichling, also independently investigated the multiple arch dam, but with no actual construction. (Noetzli: 1927, p. 470; Jorgensen: 1917, pp. 890-92, 894-97, 899-900.) By 1906, John S. Eastwood also began experimenting with designs for reinforced concrete multiple arch dams for the Big Creek project, while George Ladshaw of Spartanburg, South Carolina, received a patent for a closely related dam design, termed by Ladshaw a "multi-differential" dam. Ladshaw filed a patent infringement complaint against both Eastwood and Williams in 1911-12. (Jackson: 1986, pp. 427-28, 706-07.) In 1908 Eastwood's Lake Hume Dam saw construction, the first multiple arch dam built since the 1806 Meer Alum Dam.

At the time of Edward Wegman's eighth edition of *The Design and Construction of Dams* in 1927, the St. Francis Dam in Southern California had not yet failed and multiple arch dams, although widely disliked among the engineering community and tainted by the Gleno Dam failure, received a full section with seven chapters (100 pages) of commentary by younger engineer Fred A. Noetzli. Noetzli, educated in Zurich and possessing a civil engineering degree of 1911, had worked in Italy in 1914-15 before immigrating to the United States in 1917. From 1918 until his death, he designed dams, with four American multiple arch and multiple dome dams to his credit, 1924-28, and one Brazilian multiple arch dam of 1929-30. He further reported to the Tirso Hydroelectic Company in Italy on the developments in American multiple arch dams and was well aware of why the Gleno had failed. (Baumann: 1934, pp. 1496-97.) Of striking note, Noetzli, who came of professional age in the shadow of Maillart, became heir to Eastwood's multiple arch, improving it and writing about it for the engineering press. By 1927 about 60 multiple arch dams had been built worldwide, with about three-fourths of the dams in the United States and nearly one-third of the dams Eastwood's. Of these dams, all but four were built entirely of reinforced concrete; only the low Meer Alum Dam of 1806 was of masonry exclusively. Three other multiple arch dams combined cut-stone and brick masonry with reinforced concrete, failing in the single instance of Gleno where the masonry served as the foundation. Nearly two-thirds of the constructed multiple arch dams were less than 75 feet high, with only 10 climbing above 150 feet. In the intermediate group, those of between 75 and 150 feet, Eastwood designed six dams. Eastwood, alone, designed fully one-third of the higher

multiple arch dams worldwide. Multiple arch dams were associated with hydroelectric development about one-third of the time, with substantial power-generating function in France and Italy. These two countries sought to industrialize at the cheapest cost possible post-World War I.

Of the select highest multiple arch dams, those above 150 feet in height, almost all were designed and built in the 1925-27 years. Eastwood designed two of these 10 dams, and Eastwood alone designed more than one successful, high multiple arch dam during the 1919-24 years. Eastwood's Little Rock Creek Dam (175 feet) and Luigi Kambo's Tirso Dam (239 feet) were the earliest of the group. Of the 10, too, Noetzli designed two dams, one of which was an addition to Eastwood's Mountain Dell Dam in Utah (1915-17, at 110 feet; modified in 1924-25 to 150 feet). All of the 10 high multiple arch dams were built in Western America and Canada (seven, with four in California), and in Italy (five). Half of these produced electricity. Only two cleared the 175-180-foot height, a 1926-27 hydroelectric dam in Arizona (256 feet) and the Tirso in Italy of 1919-23 (of combined hydroelectric and irrigation function). Clustered in the middle 1920s, five of the multiple arch dams were of 170-180-foot height, including that at Little Rock Creek. Little Rock Creek's notice as "the highest multiple arch dam in the world" in 1924 was technically true for a fully reinforced concrete structure, but was immediately superceded in 1925 by an Italian power dam and had already been surpassed in 1923 by the reinforced concrete-masonry dam at Tirso. Special precedent-setting status really accrued to Little Rock Creek for its height as a 1919 all-reinforced concrete design, extremely early for its 175-foot height. Multiple arch dams, overall, were a phenomenon of Western America and Northern Europe: 18 dams were built in California, one in Oregon, one in Utah, two in Idaho, three in Arizona, and one in British Columbia, Canada; seven were built in Italy, two in France, one in Germany, three in Sweden and one in Russia. Low multiple arch dams appeared in New York, Michigan, Minnesota, and Iowa, with a single high (114 feet) multiple arch dam built in North Carolina in 1927.(Noetzli: 1927, pp. 470-519; Jackson: 1986, pp. 549, 706-07.)

Only a handful of engineers designed more than a single multiple arch dam. These men represented a mixture of traditional professionals from Michigan and New York, Eastwood from California, and Northern European engineers. Gardiner Stewart Williams (18 -1933), of Cornell and the University of Michigan, designed nine low multiple arch dams for Michigan, Minnesota, Iowa, and Russia between 1910 and 1930. Like Eastwood, he was among those engineers who had designed multiple arch dams at the turn of the century; Eastwood interpreted Williams as his only true colleague and as a professional with a commitment to the dam type. (Jorgensen: 1917, pp. 899-900; Jackson: 1986, pp. 548-51, 706-07.) Working in association, three New York engineers contributed to multiple arch design. William Barclay Parsons (1859-1933), Harry de Berkeley Parsons (1862-1935) and Walter Jules Douglas (1872-1941) designed five low-to-moderate multiple arch dams in New York (two in 1910, two in 1913 and one in 1921-23). The Parsons brothers designed many reinforced concrete structures and rail systems, including reinforced concrete bridges and docks, as well as subway, interurban transit systems

and canals. As early as 1900 and sustained into the 1920s, the Parsons designed for hydroelectric plants. (Klapp and Brinckerhoff: 1933, pp. 1485-92; Ridgway: 1936, pp. 1617-20.) Douglas worked first as a bridge engineer in Washington, D.C., traveling throughout Northern Europe in 1904 studying bridge design there. His bridges, like Maillart's, emphasized structural art made possible through the medium of concrete. Douglas became associated with New York engineer William Barclay Parsons (1859-1933) in 1909, the two dams of 1910 designed in partnership. Later in his career he designed with the younger Parsons for an 80-foot multiple arch dam as a part of a public works project at Sherman Island. (Foster and Halmos: 1942, pp. 1740-46; Jackson: 1986, pp. 551-53.) Those engineers trained in Europe who designed multiple arch dams included engineer Considère, who designed in France; Lars R. Jorgensen, a Danish engineer who immigrated to first to New York (1901) and then to Los Angeles-San Francisco (1903); and Swiss Noetzli, who arrived in Los Angeles in 1917. (Downs: 1937, p. 727; Baumann: 1934, pp. 1496-97.) These three men, like the Parson brothers and Douglas, brought considerable hydroelectric experience to their design of multiple arch dams. Considère designed two multiple arch dams; Jorgensen, also two (of 112-foot height in California, 1915-16); and Noetzli, four in California, Utah, Arizona and Brazil (three high; all 1924-30). Jorgensen and Noetzli became the major theoreticians for the multiple arch dam. (Jackson: 1986, pp. 553-61.) Eastwood's 17 multiple arch dams were unapproached for their number by any one engineer, worldwide.

Engineering commentary and discussion of the multiple arch dam began in earnest during the construction of Eastwood's Lake Hume Dam. In December 1909, Carl Grunsky, a consulting engineer trained in Germany and at this date working in San Francisco, commended Eastwood as having "ventured upon a departure which has merit." (Grunsky: December 25, 1909, pp. 582-83.) Originally settled in Stockton, near Eastwood's Central California home in Fresno, Grunsky possessed two characteristics often found in the designers of the multiple arch dam: a European engineering education and a strong interest in art. Grunsky was well known in his professional community as an oil and water color painter. (Marx: 1935, pp. 1591-95.) Grunsky's reservations about Eastwood's multiple arch dam were relatively minor. Of note, however, they elicited a second supportive response Lars R. Jorgensen, who had arrived from Denmark in 1901 and who, in 1909, worked for Frank G. Baum and Pacific, Gas & Electric in San Francisco. Jorgensen supported Eastwood's engineering calculations explicitly. Grunsky's article in the *Journal of Electricity, Power and Gas* also prompted New York's Wegman to submit a first brief history of the multiple arch dam, briefly commenting on the juxtaposed issues of cost savings and "secure water-tightness." (Jackson: 1986, pp. 311-12, 399.) In early 1911, while he was working on his second multiple arch dam at Bear Valley, Eastwood designed a multiple arch dam for the Great Western Power Company's hydroelectric project on the Feather River. Great Western Power's representative asked well-known engineer James Dix Schuyler to review Eastwood's design prior to construction. Schuyler, consulting out of Los Angeles, had been Eastwood's direct competitor for the Bear Valley Dam two years earlier, offering for it a concrete gravity design. (Jackson: 1986, p. 400.) Schuyler's critique

for the power company, the first of its type for a multiple arch dam, generally approved of Eastwood's design. Schuyler forthrightly commented that the cost might best that of the standard gravity dam by 50%. Like engineers in the years that would follow, however, Schuyler noted that the multiple arch dam would really only be his choice when a project demanded extreme cost-effectiveness; he further expressed open concerns about the multiple arch dam's ability to withstand earthquake stresses. Great Western Power sought a second review from New York's Alfred Noble. Noble's professional opinion reflected Schuyler's very closely, and both men indicated their perceived need for enhanced steel reinforcing in Eastwood's dam. Although partially built, the Big Meadows Dam never saw completion. Construction of Eastwood's multiple arch dam on the Feather River aborted in 1913, with an earthen dam started upstream. (Jackson: 1986, pp.341-47, 384, 407, 409.)

The California engineering community took up the debate over the multiple arch dam steadily between 1914 and 1930. Grunsky wrote again in 1914, discussing Eastwood's Bear Valley Dam. In another article for the *Journal of Electricity, Power and Gas*, he, like his leading contemporaries in Europe, pointed to new design made possible through the structural principles inherent in reinforced concrete. With regards to the multiple arch dam, Grunsky noted: "Now that reinforced concrete may be substituted for plain concrete and the reliability of concrete as an impervious or nearly impervious material is better understood it is quite proper to treat a relatively thin shell of this material..." (Grunsky: June 20, 1914, p. 532.) J.B. Lippincott also commented positively on Bear Valley, especially remarking on its thin concrete shell. (Lippincott: October 28, 1915, p. 854.) By 1916, Eastwood had a California competitor for a structural reinforced concrete dam in Lars R. Jorgensen. Jorgensen, who became best known for his constant angle arch dam, designed a multiple arch dam at Gem and Agnew Lakes in northeastern California for a power project. (Jorgensen: December 21, 1916, pp. 1157-59.) Perhaps due to Jorgensen's relative youth as compared to Eastwood, and to his impeccable German engineering education, it was *his* multiple arch dams that first received a full professional audience in *Transactions of the American Society of Civil Engineers*. (Jorgensen: 1917, pp. 850-906.) In the discussions following Jorgensen's formal paper, Wegman, however, seemed to begin a retreat from the multiple arch type, praising Jorgensen's analysis as useful "to all engineers who have to design such dams." Douglas, who had designed four New York multiple arch dams with the Parsons brothers by this date, stated his opinions even more severely: "All engineers who are interested in the development of reinforced concrete...know that every once in a while something 'gets by.'...the arches and the buttresses of the dams shown in the paper are unnecessarily thin." (Jorgensen: 1917, pp. 892-93.) Williams, also commenting, restricted his tone to neutrality and technical critique only. Foundations and water-tightness continued to dominate concerns. Jorgensen continued to write for the *Journal of Electricity* repeatedly in 1918, and Eastwood, typically not a participant in published group discussions, offered a single article in 1919. (Jorgensen: March 15, May 1 and August 15, 1918; Eastwood: March 15, 1919.)

A final sustained phase of professional discussions occurred during the 1924-29 years, with yet another Danish immigrant, Bernhard Faaborg Jakobsen, and Noetzli tackling the problems of determining stresses in multiple arch dams. Both men were well-educated in Northem Europe and both brought substantial experience in power projects. (Leonard: 1925, p. 1076; Jakobsen: 1923, pp. 1093-1131; Noetzli: 1924, p. 342.) At the time Noetzli wrote on his design for an improved multiple arch dam, one with more reinforcing and stiffening of buttress piers for ever-higher structures, he could proudly state that "No multiple-arch dam has ever failed...and any argument regarding what might happen in case of failure of an arch or a buttree is merely speculative." The Gleno dam, the Italian reinforced concrete multiple arch dam on masonry lower structure, failed as he submitted his article, with much loss of life and property. By 1925 the controversy surrounding the safety of the multiple arch dam had not lessened. In reviewing Eastwood's Anoyx Dam for British Columbia of 1921-24, the *Southwest Builder and Contractor* commented: "Nearly every one of the 17 dams Eastwood built has behind it a long and bitter controversy." As was consistently the case, cost savings were argued against safety issues, with the proper role of artistic design argued by many. Jakobson noted: "Eastwood has been a pioneer in dam design, and an asset to civilization. ... The one engineer promotes civilization by the savings he makes possible, and the other [the traditionalist] retards civilization, and, after all, the one may take no greater chances than the other." (Weber and Atkinson: January 16, 1925, pp. 46-47.) With the failure of the St. Francis Dam in Southern Califomia in 1928, the fears surrounding the Gleno were compounded. In near final frustration Noetzli attempted to temper the calls for rigid public agency supervision of dams. "A number of foreign countries, notably France, Germany, and Italy, have adopted rules and regulations for the design, construction, and maintenance of dams. These rules are sufficiently strict to preclude unsafe designs or constructions. On the other hand, they are sufficiently flexible so as not to restrict progress in the art unduly." (Hinderlider: 1929, p. 864.) Art, for those engineers designing in reinforced concrete and settled regarding the safety issues, closed the developmental period for the multiple arch dam much as it had opened it.

Of Eastwood's 16 completed multiple arch dams of the 1908-24 years, survival has been uneven. As of 1987-93, three remain intact, unaltered: the triple-arch, low Eagles Nest Dam (1917-18) at Warner's Ranch, San Diego County, the Argonaut Dam (1916) at Jackson and the Webber Creek Dam (1919-24) at Placerville, both in the Northern California Sierra Nevada foothills. Three other dams are abandoned: the Kennedy Dam (1914) at Jackson, the Malad (1917) in Idaho, and the Anyox (1921-24) in British Columbia. The Malad developed foundation leaks and was abandoned due to safety concems related to these leaks. The second Idaho dam, that at Fish Creek of 1919, is badly deteriorated due to the poor quality concrete used in construction. Of minor impact, four of the dams have been resurfaced: Lake Hume (1909), Los Verjeles (1913-14) and San Diequito (1918) in California, and Mountain Dell (1917) in Utah. Of intermediate impact, three dams have been strengthened for seismic safety: Bear Valley (1911), Murray (1917) and Lake Hodges (1918), all in Central and Southern California. Only one Eastwood dam has been fully removed, and thus lost to history: the Cave Creek Dam in

Arizona of 1921-23. With the seismic strengthening now under way at the Little Rock Creek Dam (1919-24) near Palmdale, another of Eastwood's multiple arch dams will be heavily altered, but will remain active. Actual safety issues could be said to be certain only for the two Idaho dams, Malad resultant from foundation leakage and Fish Creek from deteriorating concrete. Fear of failure, particularly failure resulting from earthquakes, has nonetheless been directly responsible for the altering of four more Eastwood dams. Without a catastrophic earthquake to test the fear, its reasonableness remains simply unknown.

II. ARCHITECTURAL INFORMATION

The Little Rock Creek Dam, sited on Little Rock Creek in the vicinity of Palmdale and Littlerock, California, is one of approximately 60 reinforced concrete multiple arch dams built worldwide between 1908 and 1930. [Photographs CA-8-20 through CA-8-26] Crest length of the dam is cited variously as 648 to 724 feet, with a maximum height from bedrock to the top of the structure of 170 to 175 feet. [CA-8-27] Average height above bedrock is 125 feet. Maximum width of the dam at its base is a little more than 229 feet, with a five-foot cap width. In plan, the dam is an angled structure. The downstream 15 degree 10 minute angle at buttress 12 (as identified from the west) defines the two linear segments of the dam, dividing it into one approximately 390-foot component and one approximately 300-foot component. [CA-8-32 and CA-8-42] The dam's downstream bent is unusual for any dam, of gravity or structural type, including the multiple arch type. Inclusion of the bent was to accommodate the topography of the site, specifically to avoid a deep chasm in the bedrock. Construction of the Little Rock Creek Dam required 25,000 cubic yards of concrete and 526 tons of reinforcing steel. Bedrock foundation is granite. A created reservoir is contained to the south of the dam. [CA-8-38 through CA-8-40]

The multiple arch dam type is a structural solution to dam technology. Essentially using a thin, reinforced concrete shell, Little Rock Creek Dam is articulated through 28 cylindrical arch rings, each spanning 24 feet. [CA-8-41] The arch rings are inclined at a 45 degree 38 minute angle from bedrock to the upper 13.5 feet of the dam; for the uppermost 13.5 feet, the arch rings are vertical. Thickness of the reinforced concrete rings varies from 4.7 feet at bedrock to 1.25 feet at the dam's cap, with an overall base thickness of 47 feet and a crest thickness of 12 feet. Reinforced concrete buttress walls placed between the arch rings, 29 in number, further strengthen the dam. The buttress walls are triangular in plan, varying from an upper thickness of 1.25 feet to a thickness of 4.9 to 5.6 feet at base and containing 40 pounds of reinforcing per cubic yard of concrete. Buttresses are a uniform 15 inches thick for the top 55 feet of the structure. Overall thickness for the buttresses at the top of the dam is 15 feet, at the base, 67 feet. Excavation to bedrock for buttress foundations varies from the anticipated 10 feet below the streambed to 48 feet below the streambed for buttress 20 and two adjoining buttresses. Absolute excavated depth to bedrock for these three buttresses establishes the maximum height

of the dam (cited as 173 feet in 1926). Buttresses distribute the loads imposed by the hydrostatic pressure of the stored water upon the arch rings, carrying it through to the bedrock foundation. Additional strengthening is achieved through 15 heavily reinforced tie beams set perpendicular to the buttresses and anchored in canyon wall bedrock on the east and west. The tie beams encase approximately another 40 tons of reinforcing steel. (Jackson: 1976; 1981; 1987; "Highest Multiple Arch Dam:" August 22, 1924; Eaton: November 25, 1926.)

John S. Eastwood designed three known multiple arch dams for the Little Rock Creek project, two in 1918 and one in 1919. The 1919 design saw construction in 1922-24. [CA-8-55 through CA-8-81.]

Alterations

Siphon Spillway

As designed and constructed, the Little Rock Creek Dam also featured a siphon spillway at its western edge. Siphon spillways allowed water to release from an over-full reservoir through suction action. The suction emptied water faster than traditional overflow, and in theory increased the safety assumed for a high dam holding back proportionally great acre-footage of water. Eastwood first planned to use a siphon spillway for his Big Meadows Dam in northern California of 1911-13. (Jackson: 1986, p.413.) Northern European engineers had introduced the technology and design of siphon spillways for dams as early as 1870, with Germany, France and Northern Italy employing them steadily into the early 20th century. Although not common in the United States, siphon spillway technology had been used for the Champlain branch of the New York State Barge Canal in 1910 and was featured in *Engineering News* late that year. (Ludin: April 20, 1911, pp. 467-68.) Eastwood acknowledged the siphon spillway as innovative and unusual for American dams. After the Big Meadows project aborted, he did not use a siphon spillway again until the Murray Dam of 1917 in San Diego County (117 feet high; crest of 900 feet). The Little Rock Creek Dam siphon spillway occupied the space between the first four buttresses, with four siphons between each buttress (16 total). The spillway had a discharge capacity of between 13,000 and 14,300 second-feet, a capacity that from the dam's very first years was not interpreted as sufficient to handle the pressures of reservoir water behind it. (Eaton: November 25, 1926, p.29.) In 1933 the Palmdale Water District filed an application with the State of California to cut a second emergency spillway in the rock at the western end of the dam to take pressure off the face of the dam. Although begun in late 1933, most of the work was completed in late 1936. Little Rock Creek's spillway system, nonetheless, did not stand up to rapidly accumulating debris of the repeated rainstorms of 1938. Blocked, the spillway acted as a barrier and water overtopped it. The siphon spillway barrels collapsed. The uncontrolled, sudden release of water flooded areas below the dam, destroying parts of the concrete flume, wooden trestle and concrete canals of the irrigation works. An open channel

spillway was built for the Little Rock Creek Dam in 1938-40, replacing the damaged siphon spillway of 1922-24. [CA-8-29 and CA-8-37] By 1940, at least, the siphon spillway was referred to as "the doghouse," a term apparently commonly used in the professional community for spillways and/or siphon spillways; the term does not appear to be particular to the Little Rock Creek Dam. (Cowell: September 27, 1940.)

Waterproofing the Face of the Dam

The first-built multiple arch dams leaked water through their structure, interpreted as a severe safety hazard. Many reinforced concrete dams did in fact leak during the early 20th century, including the more conservatively designed gravity dams. Fears of failure, however, were enhanced with the multiple arch dam due to its much lesser percentage of concrete; engineers assumed that increasing water pressures might break through the face of the dam. By 1927, Noetzli, in his chapter on multiple arch dams for Wegman's *The Design and Construction of Dams*, commented: "On account of the relatively small thickness of the arches of multiple-arch dams, it is most desirable to waterproof the upstream face." He noted that the preferred waterproofing was a layer of reinforced gunite, one to two inches thick. Earliest waterproofing for multiple arch dams had varied, with first efforts typically using a asphalt-base paint ["Intertol"]. (Noetzli: 1927, p.469.) Although required by the State of California in 1932, waterproofing the dam's face did not occur until 1938-40. The natural rock outcropping on the downstream face of the 1938-40 open channel spillway also was gunited, in 1964. (Palmdale Irrigation District: October 29, 1964.) [CA-8-36]

Outlet Screen

As a part of the 1938-40 repairs to the Little Rock Creek Dam, following the flood of March 1938, the outlet screen was extended. (Schoeller: November 30, 1940.) The outlet screen is incorporated into the downstream face of the dam, with outlet pipes emptying into the streambed of Little Rock Creek. Further modifications to the outlet screen were undertaken in 1982. (Palmdale Water District: December 1, 1982.) [CA-8-28, CA-8-30, CA-8-31, CA-8-33 through CA-8-35]

Irrigation Canal System

The oldest portion of the irrigation system immediate to the dam, extant today, dates to 1912-13. Designed by engineer T.D. Allin and built by the Bent Brothers for the Palmdale Water Company, a reinforced concrete flume extended from the system's headworks, a site now to the near north of the face of the dam. The complete irrigation works followed the 1896 alignment of the South Antelope Valley Irrigation Company. The Allin-Bent Brothers reinforced concrete flume, a segment of a canal system that was largely earthen in 1912-13, measures 1590 feet in

length, with dimensions of seven feet wide by five feet deep. (Bent: 1912, 1913; Palmdale Land Company: 1914; Lippincott: 1915, p.2.) The structure's horizontal cross-bars are distinctive, making this segment of the overall system clearly identifiable. At points the reinforced concrete flume is tightly constructed to undercut occasional large rock outcroppings prominent in the landscape of the river canyon. In the 1938 floods, 250 feet of the 1912-13 reinforced concrete flume washed out and was rebuilt. (Palmdale Irrigation District: April 18, 1938.) The Littlerock Creek Irrigation District also improved its canals, 1914, lining the first three miles of its irrigation distribution system with concrete. (Adams: 1916, pp. 91-92.) [CA-8-48 through CA-8-50]

A 400-foot long wooden trestle continuing the system north of the reinforced concrete flume is assumed to have been built in 1912-13, reinstating a trestle first in place in 1896. This structure completely washed out in 1938 and was rebuilt, existing today, as rebuilt in 1938-40. One section of the wooden trestle was substantially modified with welded steel components in late 1957. (Palmdale Irrigation District: April 18, 1938; Schoeller: November 30, 1940; Felt: November 26, 1957.) [CA-8-43 and CA-8-44]

The Bent Brothers, in a further improvement of the irrigation works concurrent with construction of the dam, 1922-24, designed and built a reinforced concrete canal of 830-foot length extending northwestwards from the north end of the wooden trestle. The 1922-24 canal also washed out completely in the 1938 floods and was rebuilt, 1938-40. (Palmdale Irrigation District: April 18, 1938.) In type, the 830-foot reinforced concrete canal is similar to the earlier reinforced concrete flume; each, however, are distinct in design and construction. [CA-8-51]

Also as a part of 1922-24 dam construction and irrigation works improvements, the Bent Brothers designed and built the underground flume from the downstream face of the dam to a connection with the 1912-13 reinforced concrete flume pre-existing above-ground. [CA-8-45 and CA-8-46] Two reinforced concrete box outlets/points of access for the underground flume are located at intermediate sites between the dam and the 1912-13 flume above-ground. Other segments of the irrigation works to the northwest of the 1938-40 rebuilt reinforced concrete canal, originally earthen, were lined with cobble-stones and concrete as a traditional ditch system. These linings are assumed to be post-1940. [CA-8-47] The Littlerock Irrigation District diversion valve, of 1932, is sited at the edge of the Civilian Conservation Corps camp of 1933. [CA-8-52] In addition, tunnel and drop box construction and modification has occurred several times in points along the system. [CA-8-53 and CA-8-54]

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PART IV. PROJECT INFORMATION

Designed by Woodward-Clyde, with on-site construction engineering management by Dames & Moore, the structural rehabilitation and expansion of the Little Rock Creek Dam is a 12.2 million dollar effort, 1993-94. Primary components of the project include a roller-compacted reinforce concrete buttress on the downstream face of the dam and a 12-foot high reinforced concrete cap across the existing dam crest. The buttress will be structurally integrated with the face of the original dam, from the eastern rock wall to the western rock wall of the Little Rock Creek canyon. The reinforced concrete cap along the crest also will be structurally tied into the original fabric of the 1922-24 dam. Once the buttress is in place, the downstream face of the dam, as designed and built, will no longer be visible. Placement of the reinforced concrete cap along the original dam's crest will require demolition of the walkway railing at the top of the dam, and will require modifications to the channel spillway. The 1993-94 buttress and cap will allow the reservoir behind the dam to be raised,effectively doubling the acre-foot capacity of water storage. In addition to creating increased storage, the structural rehabilitation and expansion of the Little Rock Creek Dam will satisfy nearly 70 years of controversy over the dam's performance in a severe earthquake or 100-year flood. Due to the dam's immediate proximity to the San Andreas fault, seismic issues are paramount.

This Historic American Engineering Record (HAER) documentation of the Little Rock Creek Dam is an addendum to the HAER report previously transmitted to the Library of Congress in 1981 and was prepared in accordance with a Memorandum of Agreement among the Little Rock Creek Irrigation District, Palmdale Water District, California Historic Preservation Officer, Forest Service, Army Corps of Engineers, and Advisory Council on Historic Preservation. The documentation was prepared by Karen J. Weitze. She was assisted by Denise Bradley, Michael Corbett, David Powers, Gene Davis, and Lorain Lilburn. Large format photography was prepared by David G. De Vries. The documentation was completed between June 1993 and January 1994.

ADDENDUM TO
LITTLE ROCK CREEK DAM
(LITTLE ROCK DAM)
(PALMDALE DAM)
Littlerock Vicinity
Los Angeles County
California

HAER No. CA-8

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